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P.O. Box 47
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FEBRUARY 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Final technical results are presented for a program dealing with the placement of nickel-zinc batteries in specific military applications, namely the BQM-34A and the PQM-102 Remotely Piloted Vehicles (RPV's). The nickel-zinc system was selected for these applications because RPV's demand a high quality secondary battery that offers a compromise between long life (calendar and cycle) and low weight and volume.

2.0 Abstract (continued)

Initial program tasks included developmental cells and batteries to include cycle life testing of various separator materials, high rate/low rate temperature discharges with various types of nickel electrodes, zinc electrode substrates, and charge methods. Ultimately, program tasks included the development of the nickel-zinc system into the two candidate batteries for calendar and cycle life testing qualification testing, and flight testing the two batteries in operational RPV's.

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SECTION I
MAR-5013

1.0 INTRODUCTION

The objective of this portion of the program was to develop the technology necessary for long-life, low cost, rechargeable nickel-zinc batteries as a replacement for existing lead acid batteries used in BQM-34A remotely piloted vehicles. The nickel-zinc batteries herein described (Eagle-Picher Part No. MAR-5013) are to be physically and electrically interchangeable with existing lead acid batteries. The general technical requirements for the nickel-zinc battery are:

1) Battery voltage shall be compatible to the vehicle electrical system. (28 V. nominal)
2) Battery charging requirements shall be compatible to existing ground charging equipment.
3) Battery weight shall not exceed 30 pounds.
4) Battery capacity shall be greater than 20 ampere-hours.
5) Battery calendar life shall exceed 3 years with a projected design goal of 5 years.
6) Battery cycle life shall exceed 120 cycles with a projected design goal of 200 cycles.

Primary advantages for the selection of the nickel-zinc battery system as a replacement for the existing lead acid batteries used in the BQM-34A target drones are:

1) The secondary nickel-zinc system is able to provide superior Amp-Hr capacity with respect to volume as compared to the existing lead acid battery system. Only marginal capacity has been obtained from the existing lead acid batteries due to vehicle volume and weight limitations. Nickel-zinc systems are able to incorporate a higher energy in the limited vehicle volume and weight restrictions.

1.0 INTRODUCTION (continued)

2) The nickel-zinc battery is capable of providing better high rate performance while maintaining a high energy package. Specifically, the nickel-zinc battery is capable of delivering greater than 12.5 AH at the 45 Amp discharge rate.

3) The nickel-zinc battery will offer better cycle life under the high rate discharge conditions.

2.0 DEVELOPMENT AND EVALUATION

The objective of the Development and Evaluation portion of this part of the program was to evaluate various separator materials, nickel electrode material loading, zinc electrode composition, plate configuration designs, mechanical components, charging methods, and high temperature/low temperature performance in order to determine the most applicable cell designs for the two candidate batteries. Primary investigations were conducted with test cells similar in size to the MAR-5013, however, data generated from these investigations was applicable to the larger MAR-5011 battery discussed in the second section of this report. Data was generated in three series of developmental test cells.

2.1 Development and Evaluation - First Series

Twelve cells were constructed for testing and evaluation purposes in the First Series. Test cell variables and cycle test methods are described in Table 1. Cell characteristics for single plate configuration cells and double plate configuration cells are outlined in Table 2.

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation-First Seris of Test Cells (continued)

TABLE 1

FIRST SERIES OF DEVELOPMENT TEST CELLS

Cell Number	Separator	KOH	Positive Configuration	Test Method
1,3	1	31%	Single	1
3.4	1	31%	Single	2
5,6	1	31%	Double	1
7,8	1	31%	Double	2
9,10	2	31%	Single	1
11,12	1	36%	Single	1

Separators

1. +, pellon, Celgard 3501, cellophane, Celgard 3501, cellophane, pellon, -
2. +, pellon,Celgard 3501, cellophane, Celgard 3501, cellophane, Celgard 3501, cellophane, pellon -

Test Methods

1. Cycle Test - 12.5 Amp. discharge for one (1) hour and twenty (20) minutes, followed by a five (5) hour constant potential charge at 1.90 volts/cell with the current limited to 5 amps.
2. Cycle test - 38 Amp. discharge for twenty-three (23) minutes followed by a five (5) hour constant potential charge at 1.90 volts/cell with the current limited to 5 amps.

TABLE 2

FIRST SERIES CELL DESIGN

SINGLE PLATE CONFIGURATION

Number of cells = 8

Number of electrodes = 12 Positive/13 Negative

Electrode Area = 7.48 in^2

Current Density (12.5 Amp Discharge) = .07 $Amps/in^2$

Current Density (38 Amp Discharge) = .21 $Amps/in^2$

Positive Theoretical Capacity = 18.2 AH

Negative Active Material Loading = 1.32 gm/in^2

DOUBLE PLATE CONFIGURATION:

Number of cells = 4

Number of electrodes = 6 Double Positive/7 Negative

Electrode Area = 7.48 in^2

Current Density (12.5 Amp discharge) = .14

Current Density (38 Amp discharge) = .42

Positive Theoretical Capacity = 18.2AH

Negative Active Material Loading = 2.63 gm/in^2

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation - First Series (continued)

All cells contained conventionally vaccum impregnated nickel electrodes loaded at .7 gm/in^2. These electrodes were used either individually (single configuration) or back-to-back (double configuration) to form double electrodes. The double electrode configuration results in a lower cell surface area, but provides more ampere-hour capacity in the same weight and volume.

The cells were constructed in Eagle-Picher's standard 20 AH case because the BQM-34A (MAR-5013) cell case was not available at construction time. The rates of discharge for the cycle test were adjusted from the intended 15 and 45 amp rates to 12.5 and 38 Amp to account for the difference in cell surface area between the standard 20 AH Eagle-Picher cell case and the new BQM-34A cell design.

2.1.1 First Series Test Objectives

The objectives for this group of cells were:

1) Evaluate the cell life for the various separator systems.

2) Compare the discharge performance and cycle life of the double positive electrode configuration to the larger cell surface area of the single positive electrode configuration under both normal and high rate discharges (12.5A and 38A).

3) Determine the effect of electrolyte concentration on cell life, specifically as a degradation function on cellophane.

2.1.2 Tests Discussion

The cells were formed and subjected to a 15 Amp rate of discharge. The initial discharge is shown in Figure 1. As shown on the graph, the double positive cells experienced a lower discharge voltage. This lower performance voltage was

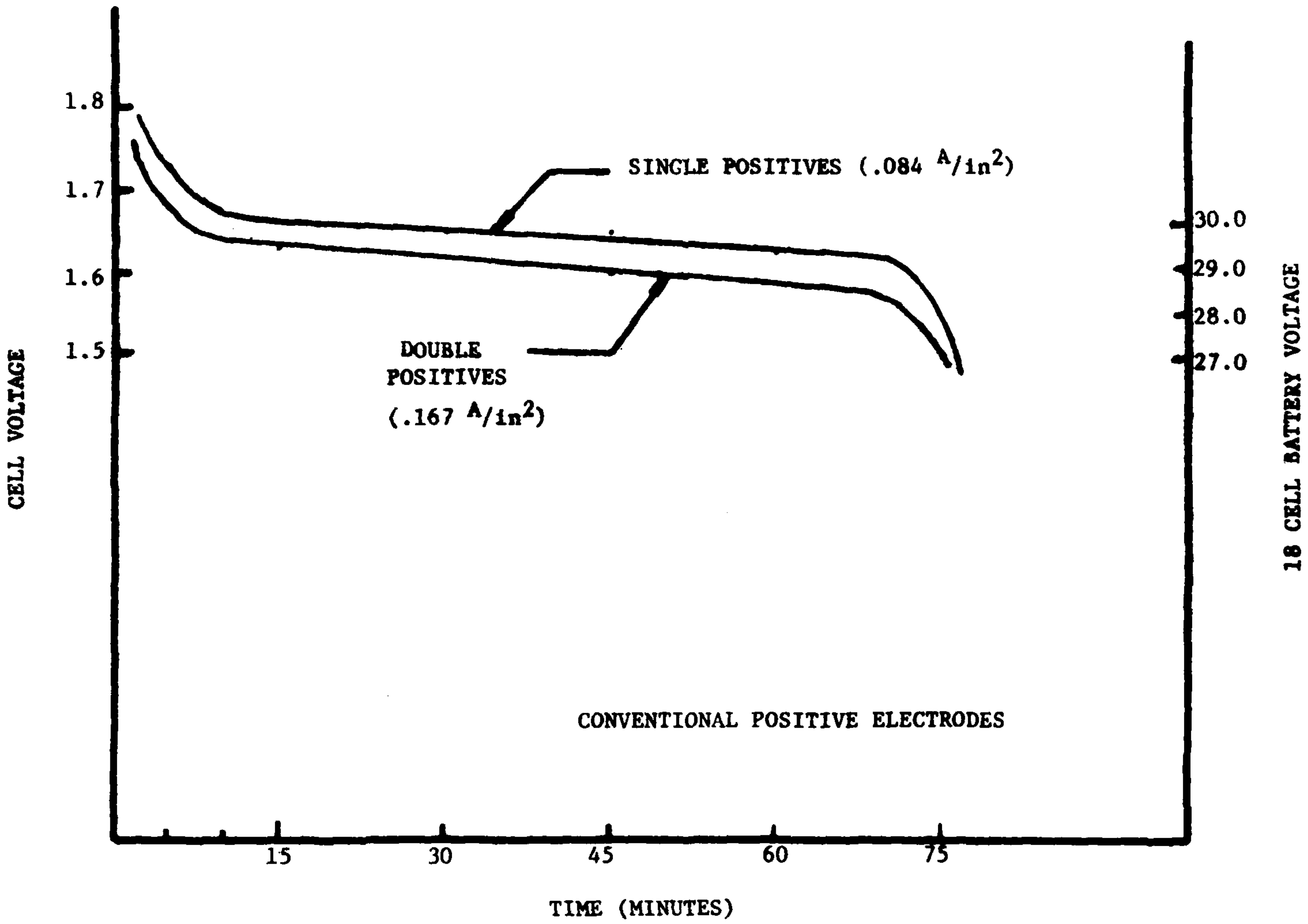

FIGURE 1

DEVELOPMENT TEST CELLS - SERIES NO. 1
75°F - 15 Amp Discharge

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation - First Series

2.1.2 Tests Discussion (continued)

expected since these cells contain only half of the surface area of the single positive cells. The advantage of the double positive configuration over the single positive configuration is an increase in cell ampere-hour capacity by the addition of plates, however, the cells in this test configuration were intentionally constructed with the same ampere-hour capacity as the single configuration plates in order to keep all cells at the same capacity for testing convenience.

The second discharge of the test configuration was performed at a 38 Amp rate. Discharge results are shown in Figure 2. At the 38 Amp rate, a greater voltage differential between the single and double positive electrodes was evidenced, however, at the conclusion of the First Series tests, the double electrodes cycled as well as the single electrodes.

After the first two discharges, the cells were split into their two respective test methods for cycling testing. Cells 1,2,5,6,9, 10, 11, 12 were electrically connected in series and tested as a battery. Cells 3,4,7, and 8 were electrically connected in series and tested as a battery. All twelve (12) cells were physically assembled into a single stainless steel battery box to simulate usage as an RPV battery.

The cells had completed the following number of cycles at the conclusion of the First Series testing as shown in Table 3.

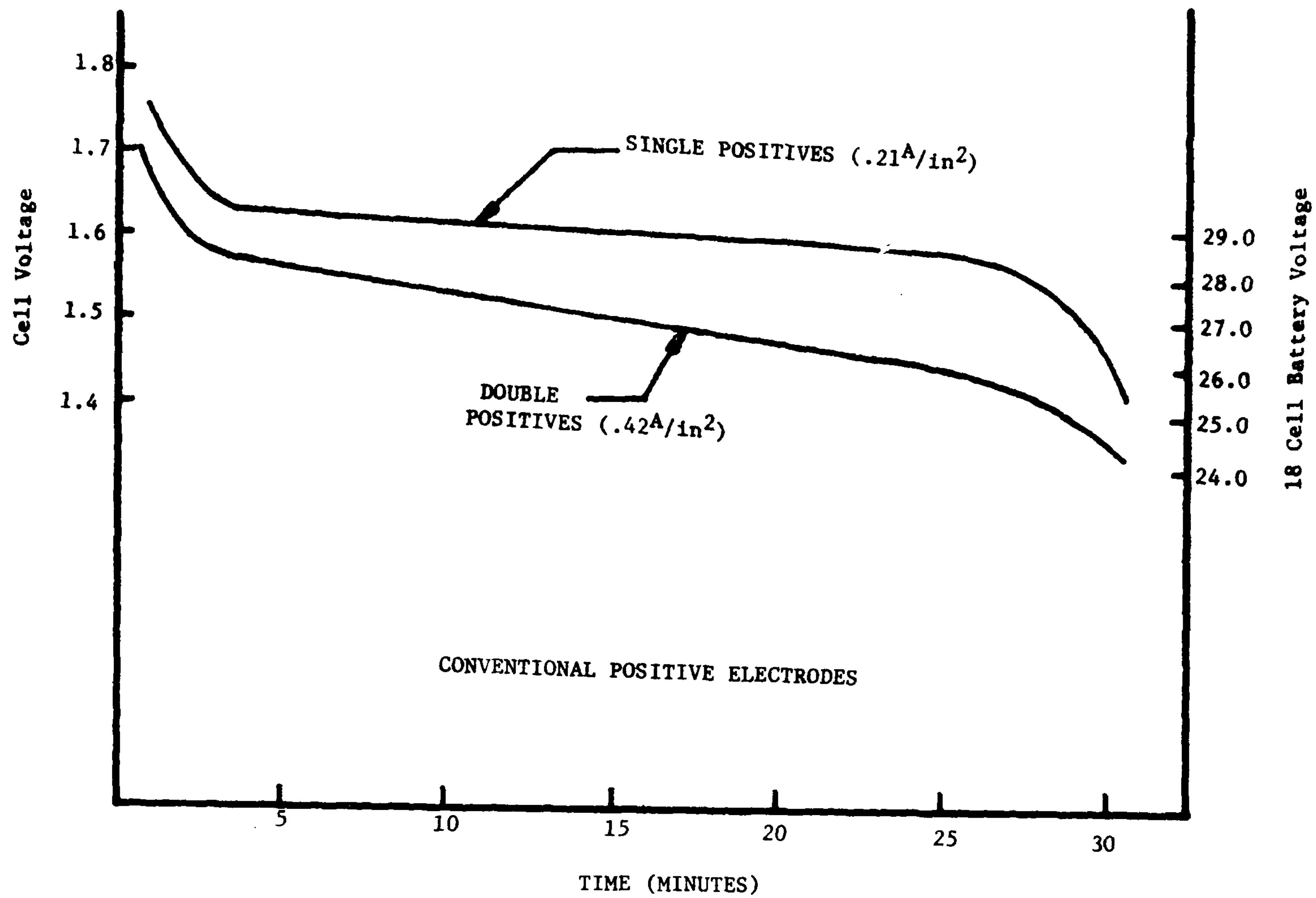

FIGURE 2

DEVELOPMENT TEST CELLS - SERIES NO. 1
75°F - 38 AMP DISCHARGE

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation - First Series

2.1.2 Test Discussion (continued)

TABLE 3

CYCLE STATUS - FIRST SERIES

Cell Number	Cycle Status	Cell Condition
1	40	Positive electrode shape changes
2	176	Mechanical Failure-positive tab
3	163	Testing discontinued
4	163	Mechanical failure-terminal
5	40	Positive electrode shape changes
6	158	Separator penetration
7	95	Short, unknown cause
8	163	Testing discontinued
9	365	Testing discontinued
10	365	Testing discontinued
11	75	Separator penetration
12	124	Mechanical Failure-terminal

Testing period for the 12.5 Amp rate of discharge cells was conducted from February 1979 to January 1980. Testing period for the 38 Amp rate of discharge cells was conducted from February 1979 to August 1979.

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation - First Series

2.1.2 Test Discussion (continued)

At test suspension of the 12.5 Amp discharge group of cells, only cells #9 and #10, remained in the test configuration. Cells #9 and #10, at 365 cycles, had achieved more cycles than necessary for RPV applications, Table 4 lists randomly selected end of discharge voltages for the cells in this group throughout the testing period. Discharge time was adjusted throughout testing as the cells accumulated cycles and began to lose capacity. Figure 3 shows the percent rated capacity removed from the cells vs. the number of cycles.

Cycle testing of the high rate cells (38 Amp discharge) was suspended because the cells had achieved a satisfactory number of cycles for RPV applications. Table 5 lists randomly selected end of discharge voltage for the cells in this group throughout the testing period. As in the case of the lower rate cells (12.5 Amp discharge), discharge time was adjusted during testing as the cells began to lose capacity. Figure 4 shows the percent rated capacity removed from the cells vs. the number of cycles.

TABLE 4

FIRST SERIES TEST CELLS

END-OF-DISCHARGE VOLTAGES

12.5 Amp Rate of Discharge

Cycle No.	AH Removed	CELL NUMBER 1	2	5	6	9	10	11	12
1 Formation	18.75	1.05	1.64	1.50	1.48	1.59	1.57	1.62	1.61
3	16.67	1.59	1.62	1.55	1.57	1.59	1.58	1.62	1.60
4	16.67	1.60	1.63	1.56	1.58	1.60	1.60	1.62	1.60
5	16.67	1.60	1.62	1.56	1.57	1.59	1.58	1.61	1.60
20	16.67	1.55	1.58	0.18	1.54	1.52	0.21	1.58	1.56
21	16.67	1.55	1.59	0.18	1.55	1.54	1.00	1.58	1.56
Discharge time adjusted from 1 Hr 20 min. to 1 Hr. 15 min. at Cycle #23.									
31	15.63	1.54	1.57	1.19	1.54	1.53	1.51.	1.56	1.53
40	15.63	Shorted Cycle #40	1.56	0.16	1.52	0.15	0.20	1.55	0.21
41	15.63		1.56	Shorted Cycle #41	1.52	1.54	1.51	1.55	0.20
42	15.63		1.56		1.53	1.55	1.54	1.56	1.40
43	15.63		1.58		1.55	1.58	1.58	1.58	1.56
47	15.63		1.56		1.51	1.51	0.20	1.54	0.20
68	15.63		1.54		1.51	0.23	0.23	1.30	0.23
75	15.63		1.53		1.49	0.21	0.21	0.28	-0.34
	ADDED ELECTROLYTE		13 cc		15 cc	13 cc	20 cc	shorted	11 cc
78	15.63		1.57		1.54	1.58	1.58		1.53
80	15.63		1.56		1.52	1.57	1.57		0.22
82	15.63		1.56		1.53	1.56	1.55		0.18
83	15.63		1.55		1.50	1.52	1.40		0.18

TABLE 4 (continued)

CYCLE NO.	AH Removed	1	2	5	6	9	10	11	12
Formation									
86	15.63		1.52		1.47	0.19	0.20		0.18
90	15.63		1.52		1.44	0.21	0.21		0.18
93	15.63		1.51		1.38	0.20	0.20		0.17
96									
	ADDED WATER		3cc		5cc	3cc			4cc
105	15.63		1.50		1.25	0.22	0.22		0.18
110	15.63		1.51		1.20	0.22	0.22		0.22
125	15.63		1.57		1.50	1.49	0.50		-2.70 Shorted
129	15.63		1.56		1.46	1.51	1.50		
151									
	ADDED WATER		7.5cc		7.5cc	7.5cc	7.5cc		
	15.63		1.53		1.30	1.40	0.20		
155	15.63		1.53		0.67	1.49	1.32		
158	15.63				Shorted				
			DISCHARGE TIME ADJUSTED FROM 1 Hr 15 Min to 1 Hr at Cycle #159						
162	12.5		1.58			1.65	1.65		
173	12.5		1.50			1.46	0.18		
176	12.5		Shorted						
192	12.5					1.52	1.52		
200	12.5					1.52	1.51		
205	12.5					1.43	1.35		

TABLE 4 (continued)

CYCLE NO.	AH REMOVED	1	2	5	6	9	10	11	12
212	12.5					1.42	1.13		
216	12.5					1.40	0.44		
224	12.5					0.17	0.22		
226	12.5					1.48	1.50		
227	12.5					0.68	0.21		
238	12.5					0.55	0.27		
241	12.5					0.62	0.23		
242	12.5					0.99	0.24		
DISCHARGE TIME ADJUSTED FROM 1 Hr.to 45 MIN AT CYCLE # 242.									
246	9.38					1.61	1.62		
248	9.38					1.56	1.62		
255	9.38					1.55	1.61		
256	9.38					1.56	1.56		
260	9.38					1.56	1.57		
269	9.38					1.53	1.54		
273	9.38					1.50	1.53		
277	9.38					1.49	1.53		
289	9.38					1.50	1.52		
301	9.38					1.51	1.53		
310	9.38					1.50	1.52		
322	9.38					1.51	1.53		
348	9.38					1.50	1.53		
356	9.38					1.45	1.50		
359	9.38					1.48	1.52		
365	9.38					1.29	1.43		

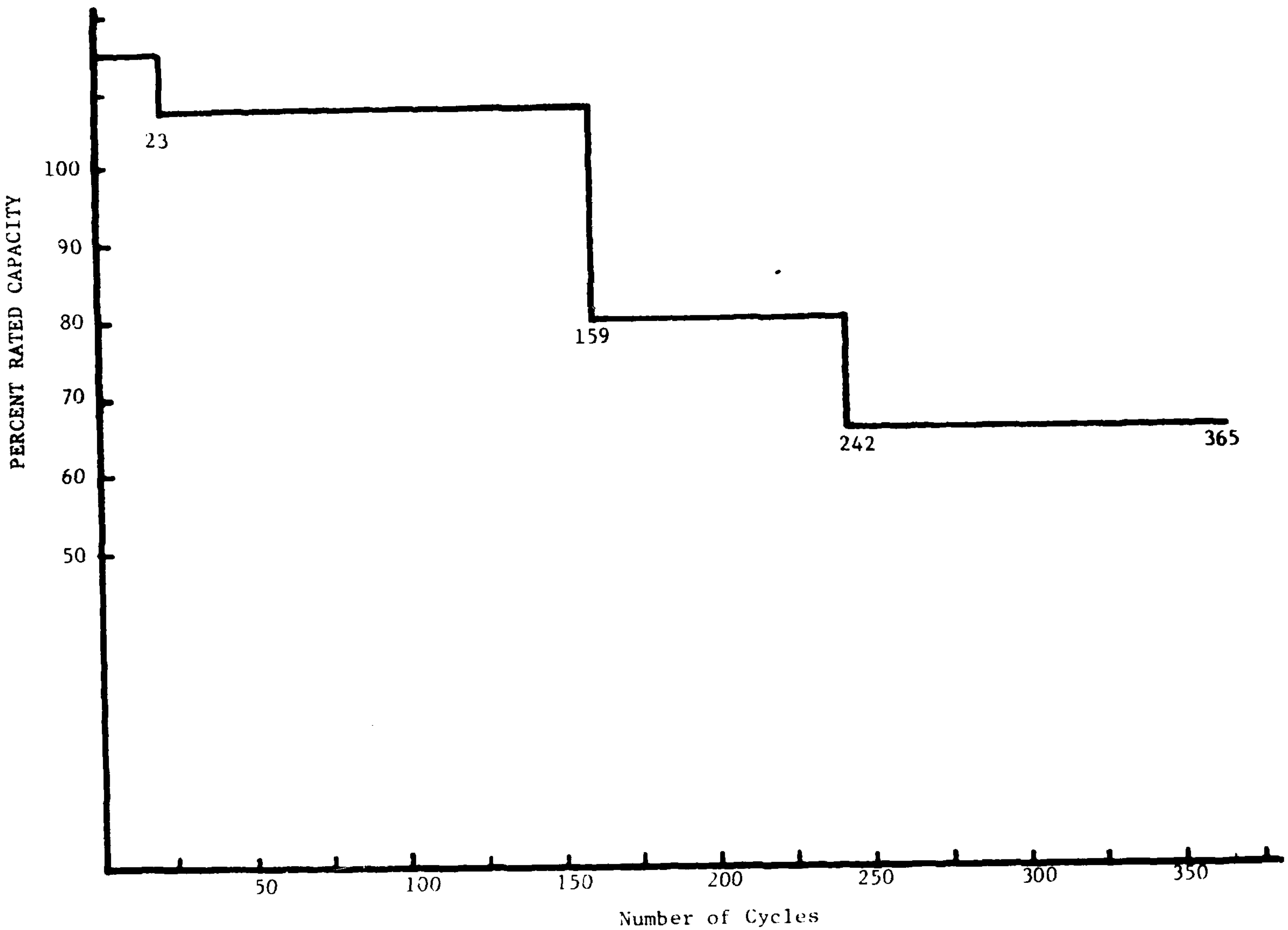

Figure 3

DEPTH OF DISCHARGE
DEVELOPMENT CELLS-FIRST SERIES
12.5 Amp DISCHARGE

TABLE 5
FIRST SERIES TEST CELLS
END OF DISCHARGE VOLTAGES
38 AMP RATE OF DISCHARGE

	CYCLE NUMBER	AMP HR REMOVED	3	4	7	8
1	Formation	18.8	1.63	1.39	1.54	0.19
3		14.6	1.56	1.55	1.45	1.45
4		14.6	1.55	1.54	1.44	1.44
5		14.6	1.56	1.55	1.44	1.44
17		14.6	1.54	1.50	1.42	1.42
30		14.6	1.52	0.12	1.35	1.36
		Discharge Time Changed from 23 min. to 20 min. at cycle # 31				
34		12.7	1.54	1.48	1.43	1.43
43		12.7	1.53	1.23	1.42	1.41
55		12.7	1.50	0.13	1.38	1.36
56		12.7	1.52	1.49	1.40	1.36
57		Added water	6 cc	10 cc	5 cc	10 cc
		12.7	1.52	1.49	1.40	1.37
58		12.7	1.49	0.10	1.38	1.35
59		12.7	1.50	0.10	1.40	1.36
60		12.7	1.51	0.10	1.41	1.37
63		12.7	1.50	0.10	1.40	1.36
65		12.7	1.50	0.10	1.38	1.35
73		12.7	1.50	0.10	1.41	1.38
83		12.7	1.49	0.10	1.40	1.38
87		12.7	1.47	0.10	1.38	1.35
95		12.7	1.47	0.14	1.36	1.32
96		12.7	1.47	0.10	Shorted at end of #95	1.15
99		12.7	1.46	1.30		1.31
100		Added Water	6 cc	10 cc		15 cc
		12.7	1.45	0.10		1.18
105		12.7	1.40	0.10		1.13
106		12.7	1.40	0.12		1.14
107		12.7	1.38	0.08		1.13
111		12.7	1.33	0.10		1.12
114		12.7	1.23	0.10		1.33
118		12.7	1.15	0.24		1.05
122		12.7	1.14	0.11		1.10
123		12.7	1.16	0.10		1.16
131		12.7	0.97	0.10		0.86
136		12.7	1.13	0.12		0.93
138		12.7	1.14	0.10		0.91
141		12.7	1.00	0.11		0.50
150		12.7	0.97	0.11		0.10
		Discharge Time changed from 20 min. to 15 min. at cycle # 151				
151		9.5	1.20	0.15		0.46
163		9.5	1.19	0.12		0.43

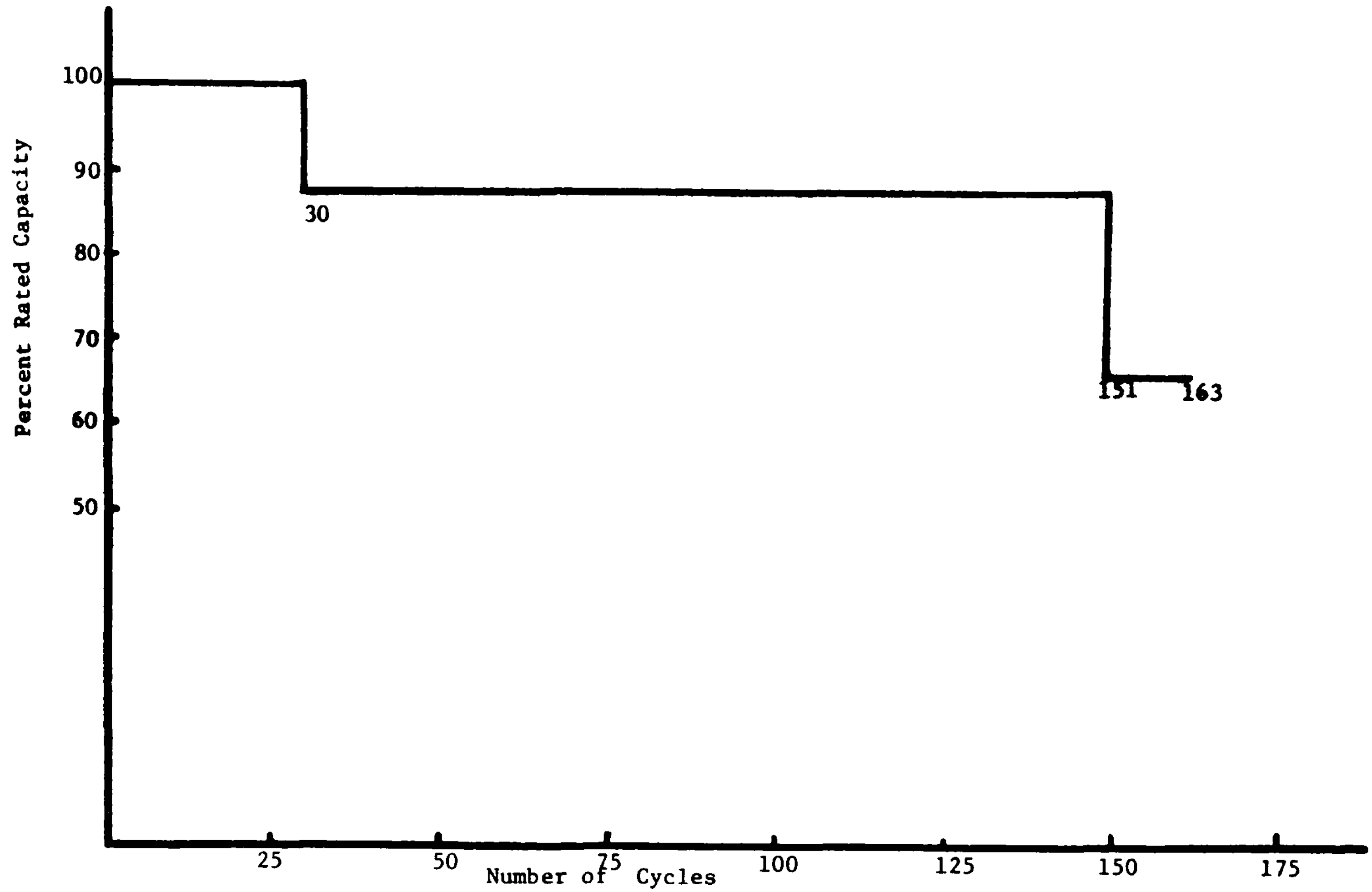

FIGURE 4
DEPTH OF DISCHARGE
DEVELOPMENT CELLS FIRST SERIES
38 AMP DISCHARGE

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation-First Series

2.1.3 Cell Failure Modes

Two cells (#1 & #5) failed as a result of positive electrode shape changes. Conventional electrodes grow as they are cycled; in this case, the electrode corners penetrated and split the separator barriers, thus allowing zinc dendrites to establish contact with the nickel electrodes and short the cells.

Two cells (#6 & #11) failed as a result of zinc dendrites penetrating the separator system, and shorting the cell. Cells #9 & #10 contained an additional layer of celgard and cellophane and at the suspension of testing, both these cells remained in the test configuration.

Three cells failed as a result of mechanical failure. Cells #4 and #12 failed as a result of caustic corroded terminals. The actual MAR-5013 cell case allows for more terminal potting area to alleviate caustic penetration around the terminals. Cell #2 failed as a result of a positive plate tab coming loose from the plate and shorting across the cell pack. Future constructed cells have a different tab and spotweld attachment.

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation-First Series

2.1.4 First Series Final Results

Final results for the First Series Development Test Cells are summarized as follows:

2.1.4.1 Separator System

At the conclusion of the First Series testing, separator system 2 (3 cellophane/3 celgard) was selected for utilization in the first actual MAR-5013 batteries instead of separator system 1 (2 cellophane/ 2 celgard). Data generated during this series did not indicate the additional layer of cellophane and celgard adversely affected cell performance, but served as additional barriers against zinc dentrite penetration.

2.1.4.2 Electrolyte Concentration

Generated data indicated a 31 percent concentration of KOH was more compatible with the nickel-zinc system instead of a 36 percent KOH concentration. Cell #11 and #12 contained 36% KOH electrolyte. Post mortem examination of these cell packs revealed extreme negative electrode shape changes and excessive amount zinc dendrites on the outside of the cell pack. Cell #11 failed as a result of zinc dendrite/separator penetration which was probably accelerated by the higher KOH concentration.

2.0 DEVELOPMENT AND EVALUATION

2.1 Development and Evaluation-First Series

2.1.4 First Series Final Results

2.1.4.2 Electrolyte Concentration (continued)

Additionally, the cellophane was more deteriorated in cells #11 and #12 compared to the rest of the cells in the configuration.

2.1.4.3 Electrode Configuration

The double electrode configuration demonstrated adequate cycle life under both normal discharge rate (12.5 Amps) and high discharge rate (38 Amps) for RPV applications. Based on the First Series data, the double electrode configuration was utilized in the MAR-5013 in order to increase ampere hour capacity in the same weight and volume single electrodes would occupy.

2.2 Development and Evaluation - Second Series

Twelve cells were constructed for testing and evaluation purposes in the Second Series, Test cell variables and cycle test methods are described in Table 6. Cell characteristics are described in Table 7.

2.0 DEVELOPMENT AND EVALUATION

2.2 Development and Evaluation - Second Series (continued)

TABLE 6

SECOND SERIES OF DEVELOPMENT TEST CELLS

Cell Number	Separator		KOH	Negative Electrode
1,2	2		31%	Standard
3.4	3		31%	Standard
5,6	3	Buffered 22% Boric Acid by wt.	31%	Standard
7,8	1		31%	Standard
9,10	4		31%	CdO Additive (2% by wt.)
11,12	4		31%	Zn & ZnO Mixture (25/75 by wt.)

Separators

1. +, pellon, 3400 Celgard, cellophane, 3400 Celgard, cellophane, pellon,-
2. +, pellon, 3400 Celgard, cellophane, 3400 Celgard, pellon,-
3. +, pellon, 4 layers 3400 Celgard, pellon,-
4. +, pellon, 3501 Celgard, cellophane, 3501 Celgard, cellophane, pellon,-

Test Methods (Automatic Cycle System)

Cycle Test - 12.5 Amp discharge for one (1) hour and fifteen (15) minutes followed by a five (5) hour constant potential charge at 1.90 volts/cell with the current limited to 5 Amps.

2.0 DEVELOPMENT AND EVALUATION

2.2 Development and Evaluation - Second Series (continued)

TABLE 7

SECOND SERIES CELL DESIGN
STANDARD FEATURES

Cell Case - Eagle-Picher Standard 20 AH

Number of Electrodes - 12 Positive/13 Negative

Electrode Area - 7.48 in^2

Current Density - .07 A/in^2

Positive Theoretical Capacity - 18.2 AH

Negative Active Material Loading - 1.32 gm/in^2

2.2.1 Second Series Test Objectives

The test objectives for this group of cells were:

1) Evaluate cell life for each of the various separator systems.

2) Determine the effect of buffered electrolyte on cell calendar life. In theory, buffered electrolyte reduces the soluability of zinc in the electrolyte and delays the process of zinc dendritic growth.

3) Compare the effect of various negative electrode additives on cycle life. The CdO additive, in theory, should improve cycle life, reduce shape changes in the negative electrodes, and reduce the gasing of the negative electrode.

2.0 DEVELOPMENT AND EVALUATION

2.2 Development and Evaluation - Second Series

2.2.2 Tests Discussion

The cells were formed and received a 12.5 Amp. discharge. The cells were then cycle tested as described in Section 2.2. Charge performance and Amp Hr. capacity was essentially the same, regardless of separator variances, electrolyte variances, and negative electrode differences.

The cells completed the following number of cycles at the conclusion of the testing period. The completed cycles are listed in Table 8.

End of discharge cell voltage data, randomly selected throughout the Third Series testing duration, is presented in Table 9. Discharge time was adjusted throughout testing to account for reduced cell capacity. Figure 5 shows the percent rated capacity removed from the cells vs. the number of cycles completed. Testing period for the series was conducted from June 1979 to March, 1980.

TABLE 8

SECOND SERIES - CYCLE STATUS

CELL NUMBER	CYCLES COMPLETED	CELL CONDITION
1	425	Testing discontinued
2	425	Testing discontinued
3	425	Testing discontinued
4	344	Testing discontinued
5	327	Mechanical Failure Terminal
6	344	Testing discontinued
7	29	Mechanical
8	43	Short across cell pack
9	344	Testing discontinued
10	344	Testing discontinued
11	43	Short across cell pack
12	325	Failure not located-cell reversal

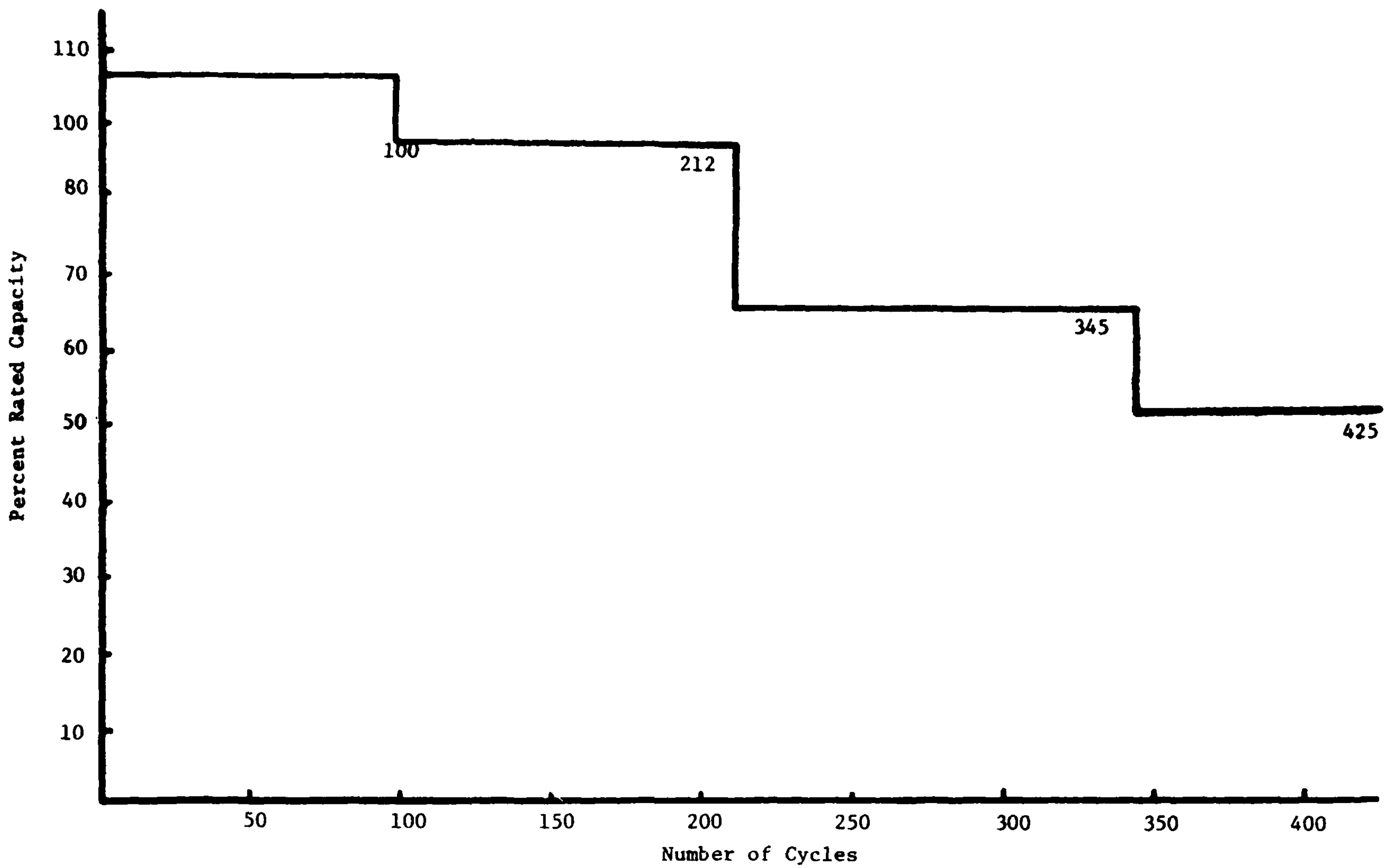

FIGURE 5
DEPTH OF DISCHARGE
DEVELOPMENT CELLS-SECOND SERIES
12.5 AMP DISCHARGE

TABLE 9

DEVELOPMENT TEST CELLS SECOND SERIES

END OF DISCHARGE VOLTAGES

12.5 A Rate Discharge

CYCLE NO.	AH Removed	Cell Numbers 1	2	3	4	5	6	7	8	9	10	11	12
1 (Formation)	20.8	1.63	1.61	1.62	1.63	1.62	1.62	0.23	0.23	1.61	0.23	1.60	1.57
15	15.6	1.61	1.59	1.61	1.61	1.60	1.60	0.24	1.57	1.59	1.54	1.58	1.57
25	15.6	1.59	1.57	1.58	1.58	1.58	1.58	0.21	1.46	1.56	0.16	1.55	1.53
33	15.6	1.58	1.57	1.58	1.58	1.58	1.58	Shorted Cycle #30	1.42	1.56	1.40	1.57	1.55
43	15.6	1.58	1.56	1.57	1.58	1.57	1.57		0.22	1.53	0.22	0.22	0.22
67	15.6	1.55	1.52	1.55	1.55	1.54	1.54		Shorted Cycle #43	1.51	0.20	Shorted Cycle #43	0.20
95	15.6	0.22	1.54	1.53	1.54	1.52	1.51			1.32	0.19		0.17
108	12.5	1.60	0.21	1.59	1.59	1.58	1.58			1.57	1.55		1.53
127	12.5	1.60	1.59	1.59	1.59	1.57	1.57			1.59	1.56		1.51
139	12.5	1.57	1.55	1.55	1.56	1.54	1.54			1.56	1.39		0.98
146	12.5	1.55	1.51	1.52	1.53	1.50	1.51			1.54	0.20		0.19
153	12.5	1.56	1.56	1.53	1.53	1.51	1.51			1.55	0.23		0.21
163	12.5	1.53	1.43	1.48	1.49	1.45	1.47			1.53	0.19		0.19
189	12.5	1.51	0.19	1.34	1.44	1.32	1.38			1.51	0.19		0.19
195	12.5	1.51	0.21	1.14	1.40	1.23	1.33			1.49	0.19		0.19
200	12.5	1.51	0.22	1.09	1.41	1.31	1.37			1.51	0.19		0.18
216	9.4	1.60	1.59	1.58	1.59	1.56	1.57			1.59	1.58		1.54
225	9.4	1.62	1.60	1.60	1.60	1.58	1.58			1.61	1.60		1.56
230	9.4	1.57	1.52	1.53	1.53	1.50	1.53			1.56	1.48		0.23
244	9.4	1.54	1.48	1.42	1.46	1.37	1.47			1.54	1.25		0.16
259	9.4	1.53	1.46	1.20	1.36	1.25	1.46			1.52	0.78		0.08

TABLE 9
DEVELOPMENT TEST CELLS SECOND SERIES
END OF DISCHARGE VOLTAGES
12.5 A Rate Discharge

(continued)

CYCLE No.	AH Removed	Cell Numbers 1	2	3	4	5	6	7	8	9	10	11	12
263	9.4	1.53	1.44	1.07	1.25	1.25	1.45			1.51	0.18		- 0.09
276	9.4	1.53	1.44	1.00	1.27	1.31	1.47			1.53	0.28		- 0.30
281	9.4	1.52	1.32	0.82	0.91	1.34	1.47			1.51	0.17		- 0.52
296	9.4	1.50	0.71	0.57	0.69	1.08	1.38			1.48	0.19		- 0.95
318	9.4	1.51	0.29	0.47	0.62	1.10	1.40			1.49	0.20		- 1.96
325	6.3	1.59	1.58	1.41	1.52	1.39	1.45			1.59	1.58		- 2.16
												*Cell Vented	
* Discharge Discontinued													
329	9.4	1.55	1.40	1.35	1.39	Shorted Cycle #327	1.51			1.55	1.22		
339	9.4	1.51	0.28	0.66	0.62		1.37			1.52	0.21		
344	9.4	1.45	0.17	0.17	0.25		1.16			1.45	0.16		
345	7.5	1.61	1.60	1.59									
351	7.5	1.56	1.53	1.53									
364	7.5	1.53	1.45	1.14									
369	7.5	1.51	1.38	0.61									
385	7.5	1.48	0.18	0.33									
397	7.5	1.48	0.18	0.30									
421	7.5	1.42	0.18	0.16									
424	7.5	1.38	0.12	- 0.11									
425	5.7			*1.05									

*Discharge Discontinued

Cell Hot

2.2.3 Cell Failure Modes

The majority of the cells in the Second Series were cycled beyond RPV cycle life requirements. Two cells, #5 and #7, exhibited mechanical failure modes that should be avoidable in the actual BQM-34A cell case design. Failure modes for cells #8 and #11, were attributed to elevated KOH levels. The cells in the second configuration were constructed in opaque cell cases which made it difficult to determine proper electrolyte levels. The BQM-34A cell case, and PQM-102 cell case are molded out of transparent SAN Plastic material to make electrolyte maintenance much easier.

Cell #12 shorted on cycle 325. It was interesting to note that this cell began reversing on the 263rd discharge and continued to become more negative on further discharges without apparently harming it or the other cells. Figure 6, shows discharges #267, #281 and #317. Post mortem examination of this cell did not reveal any evidence of short. The cell did, however, exhibit extreme negative shape changes.

Cell #3 shorted on cycle 425. Cell #3 began voltage reversal during discharge #424. Discharge #424 for cell numbers 1, 2, and 3 is shown in Figure 7. Post mortem examination of cell #3 revealed several low grade shorts throughout the entire cell pack. The low grade shorts resulted from zinc dendrite penetration throughout the four layers of separation (Celgard 3400).

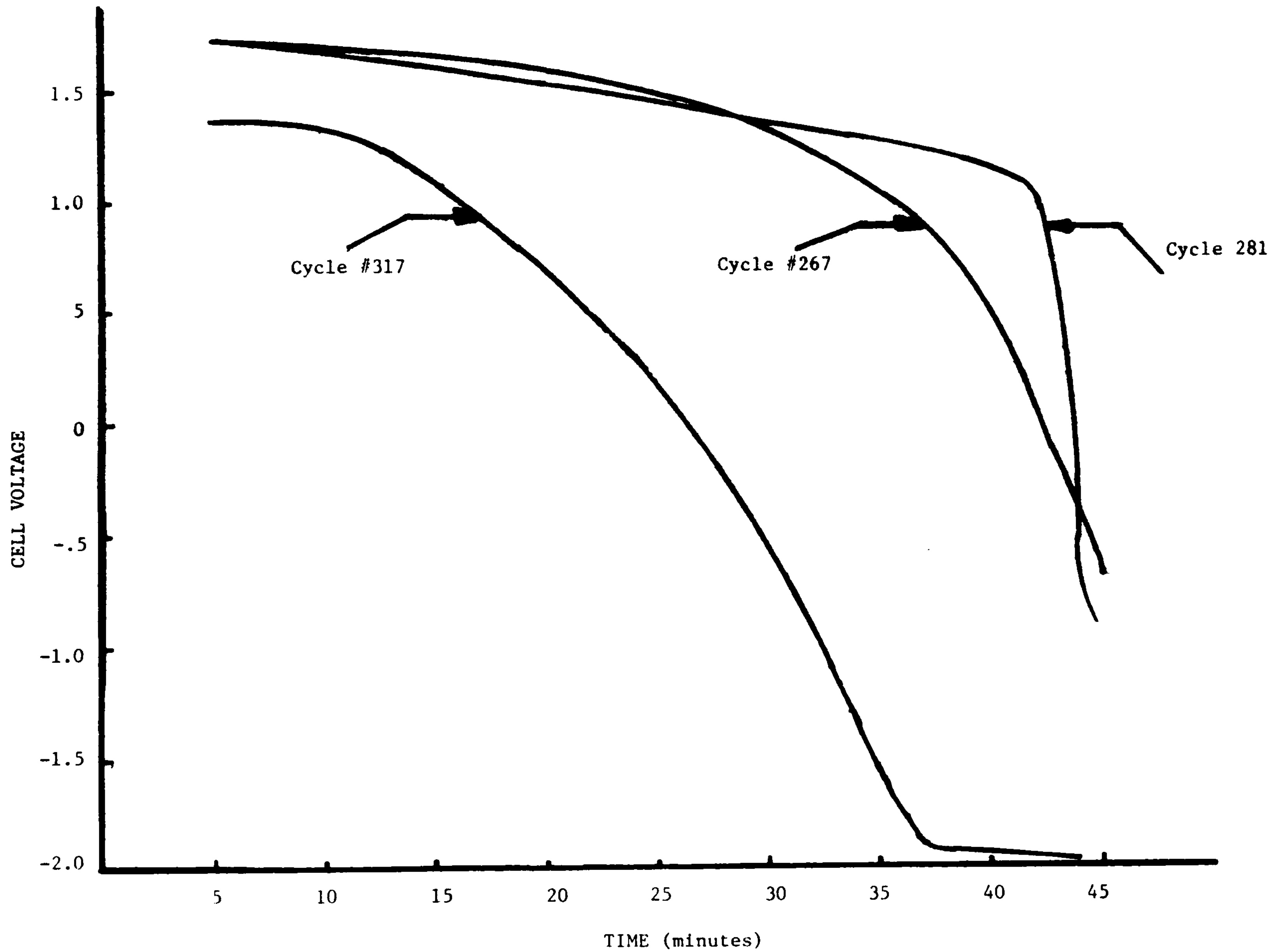

FIGURE 6
CELL REVERSAL - CELL # 12
DEVELOPMENT TEST CELLS - SECOND SERIES

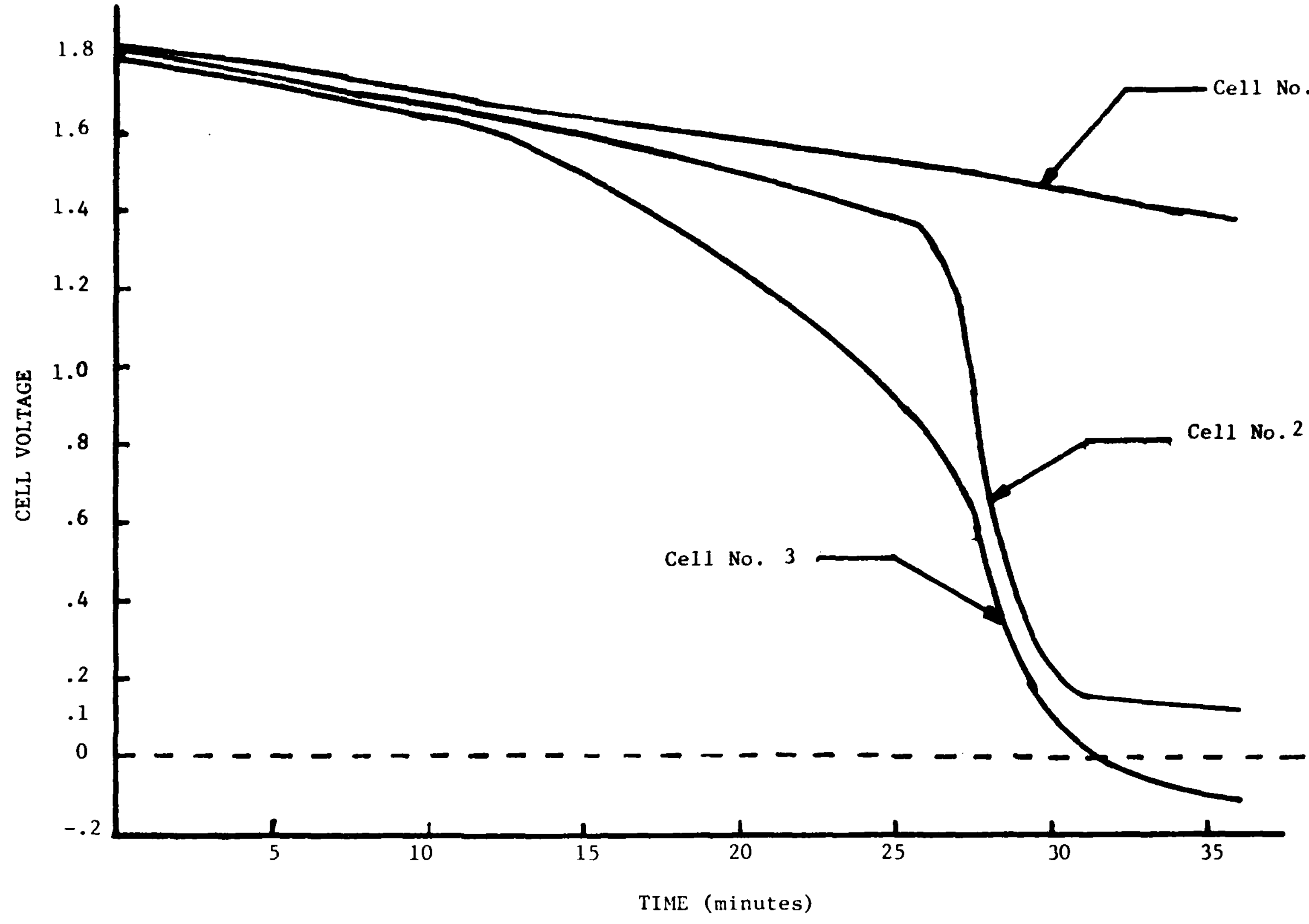

FIGURE 7

SECOND SERIES TEST CELLS
DISCHARGE 424

2.0 DEVELOPMENT AND EVALUATION

2.2 Development and Evaluation - Second Series

2.2.4 Second Series Final Results

Final Results for the Second Series Test cells are summarized as follows:

2.2.4.1 Separator Systems

In general, all the separator systems in the Second Series achieved adequate cycle life for RPV applications with the exception of separator system 1 (2 Celgard 3400/2 cellophane). Failure of cells (#7 and #8) containing system 1 resulted from a mechanical origin and elevated electrolyte level respectively rather than separation failure.

Cells #1 and #2 incorporated separator system 2. (2 Celgard 3400/1 cellophane). Cells in this group, consistently maintained a higher discharge voltage than the other cells in the test configuration.

Separator system 3 (4 Celgard 3400) was incorporated in cell numbers 3, 4, 5, and 6. Exclusive utilization of Celgard 3400 yields a separator system that does not degrade in the presence of KOH which is most advantageous with respect to prolonged calendar life. However,results obtained in the Second Series with cells incorporating this sytem displayed a slightly lower discharge performance voltage.

2.0 DEVELOPMENT AND EVALUATION

2.2 Development and Evaluation - Second Series

2.2.4 Second Series Final Results

2.2.4.1 Separator Systems

Separator system 4 (2 Celgard 3501/2 cellophane) was incorporated in cell numbers 9, 10, 11, and 12. Data was previously generated in the First Series on this separator system. Cells containing this separator system were tested for variables in the negative electrode rather than separation purposes.

Celgard 3400 was utilized in the first three separator systems rather than Celgard 3501 because 3400 Celgard Series contains a different wetting agent to reduce some of the foaming problem previously encountered with the 3501 Celgard Series.

2.2.4.2 Buffered Electrolyte

The addition of buffered electrolyte (boric acid) to cell numbers 5 and 6 did not improve cycle life when compared to cell numbers 3 and 4 which were identical with the exception of the electrolyte. It is not known if battery calendar life would have been improved with cells containing buffered electrolyte since cell cycles in this series were not generated over a prolonged time period.

2.0 DEVELOPMENT AND EVALUATION

2.2 Development and Evaluation - Second Series

2.2.4 Second Series Final Results

2.2.4.3 Negative Electrode Additives

Cells containing the CdO additive (#9 and #10) did not demonstrate improved cycle life over cells containing standard EP negative electrodes; specifically when compared to cell numbers 1 and 2. Data generated on cells containing a Zn/ZnO mixture (cells no. 11 and 12) did not cycle as well as other cells in the test configuration. Cell # 11 shorted early in cycle life due to a short across the cell pack. Cell capacity in cell #12 began fading early in cycle life.

2.3 Development and Evaluation - Third Series

Twenty-one cells were constructed for testing and evaluation purposes in the Third Series Test. Cell variables and cycle test methods are described in Table 10. Cell characteristics are described in Table 11.

2.0 DEVELOPMENT AND EVALUATION

2.3 Development and Evaluation - Third Series (continued)

TABLE 10

THIRD SERIES OF DEVELOPMENT TEST CELLS

CELL NUMBER	TEST VARIABLE	
1	*1128-196-1 HDPE/MA	+pellon, 3400 Celgard, RAI, 3400 Celgard, pellon,-
2	*1128-196-2-P6001	+pellon, 3400 Celgard, RAI, 3400 Celgard, pellon,-
3	*1128-196-3-LT-10	+pellon, 3400 Celgard, RAI, 3400 Celgard, pellon,-
4	*1128-196-4 P700 40/10	+pellon, 3400 Celgard, RAI, 3400 Celgard, pellon,-
5	*1128-200-5 Dexter Paper	+pellon, 3400 Celgard, RAI, 3400 Celgard, pellon,-
6, 7, 8, 9	+, pellon, 3400 Celgard, 3400 Celgard, 3400 Celgard, 3400 Celgard, pellon,-	
10,11,12 (control for cells 1-5)	+, pellon, 3400 Celgard, 3400 Celgard, pellon,-	
13,14,15	+, pellon, 3400 Celgard, cellophane, 3400 Celgard, pellon,-	
16,17,18, 19,20,21	Copper grid-negative	+, pellon, 3400 Celgard, cellophane, 3400 Celgard, cellophane, 3400 Celgard, cellophane, pellon,-

* Indicates RAI nickel coated separators

Test Methods (Automatic Cycle System)

Cycle test - 10 Amp discharge for two (2) hours followed by a six (6) hour constant potential charge at 1.91 volts/cell with the current limited to five amps.

2.0 DEVELOPMENT AND EVALUATION

2.3 Development and Evaluation - Third Series

TABLE II

THIRD SERIES CELL DESIGN
STANDARD FEATURES

Cell Case - MAR-5013 (modified)

Number of Electrodes 6 Double-2 single pos./7 Neg.

Electrode Area - 7.48 in^2

Current Density - (10 Amp Discharge) = .10 $Amps/in^2$

Positive Theoretical Capacity = 24 AH

Negative Active Material Loading = 1.9 gm/in^2

All cells contain conventionally impregnated nickel electrodes. The cells were constructed in the MAR-5013 cell case. The transparent MAR-5013 cell case made electrolyte level maintenance much easier for the Third Series Cell compared to the First and Second Series cells constructed in opaque ABS cell cases.

2.3.1 Third Series Test Objectives

The objectives for this group of cells were:

1) Evaluate RAI nickel coated separator for effectiveness in zinc dendrite stoppage.

2.0 DEVELOPMENT AND EVALUATION

2.3 Development and Evaluation - Third Series

2.3.1 Third Series Test Objectives (continued)

2) Evaluate cell cycle life for cell numbers 6-9.

   The separator system (4 layers celgard 3400) is not degradable in the presence of electrolyte.

3) Evaluate the use of copper grid and copper tabs in the negative electrode instead of the silver grid and silver tabs previously utilized in the negative electrodes. Escalating prices of silver have made it very desirable to completely remove silver from the nickel-zinc system.

2.3.2 Tests Discussion

Initially, the cells in the Third Series were divided into three groups for testing convenience.

The cells were formed at a 3 amp constant current rate. Cells Nos. 1 - 5 were discharged at a 12 amps constant current until the first cell in the series reached a cut-off voltage of 1.35 volts. Cell nos. 6 - 15 and 16 - 21, were discharged at 14 amps constant current until the first cell in each group reached a cut-off voltage of 1.35 volts. The different rates of discharges (12 amps vs. 14 amps) occurred because of the use of different cyclers in the automatic cycler system. Table 12 shows the amp hour capacity obtained from each variable group.

TABLE 12

THIRD SERIES FORMATION DISCHARGE CAPACITIES

CELL GROUP NUMBER	RATE OF DISCHARGE	AMP HOUR CAPABITY
1 (cells 1-5)	12	29
2 (cells 6-15)	14	28
3 (cells 16-21)	14	28

The cells have completed the following number of cycles at the conclusion of testing. Test period for the Third Series cells was from March 1980 through February 1981. Cycle status for the cells is summarized in Table 13. End-of-discharge cell voltage data, randomly selected, is listed in Table 14. Figure 8 shows the percent rated capacity removed from the cells vs. the number of cycles accumulated.

TABLE 13

THIRD SERIES TEST CELLS

CELL NUMBER	CYCLES COMPLETED
1-5	30 (testing suspended)
6-9	158
10-12	69 (testing suspended)
13-15	69 (testing suspended)
16-21	158

TABLE 14
DEVELOPMENT TEST CELLS - THIRD SERIES
END OF DISCHARGE VOLTAGES
10 AMP RATE OF DISCHARGE

CYCLE NUMBER	AMP HOUR REMOVED	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2	20	1.60	1.61	1.61	1.60	1.60	1.57	1.60	1.60	1.60	1.60	1.60	1.57	1.60	1.60	1.59	1.59	1.58	1.59	1.58	1.59	1.58
8	20	1.56	1.57	1.57	1.57	1.56	1.50	1.56	1.56	1.56	1.57	1.57	1.53	1.58	1.58	1.57	1.57	1.55	1.57	1.55	1.57	1.55
13	20	1.55	1.55	1.55	1.54	1.55	1.49	1.55	1.54	1.54	1.55	1.56	1.52	1.58	1.58	1.58	1.57	1.56	1.57	1.56	1.58	1.57
25	20	1.50	1.51	1.52	1.51	1.50	1.14	1.52	1.51	1.52	1.51	1.53	1.40	1.52	1.52	1.52	1.52	1.47	1.51	1.48	1.52	1.51
27	20	1.48	1.51	1.52	1.51	1.53	1.18	1.51	1.52	1.52	1.52	1.53	1.45	1.52	1.53	1.52	1.52	1.44	1.51	1.48	1.51	1.52
31	20	Testing Discontinued					1.51	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.51	1.55	1.55	1.55	1.55
40	20	Charge # 30					1.06	1.43	1.23	1.44	1.45	1.43	0.69	1.48	1.48	1.48	1.48	1.08	1.46	1.39	1.48	1.40
52	20						1.10	1.51	1.46	1.51	1.51	1.52	1.08	1.50	1.49	1.46	1.52	0.64	1.51	1.45	1.52	1.42
57	15						1.07	1.48	1.30	1.48	1.48	1.47	0.98	1.52	1.52	1.50	1.52	1.32	1.52	1.51	1.51	1.50
61	12.2						1.45	1.54	1.52	1.54	1.54	1.54	1.48	1.56	1.56	1.56	1.56	1.45	1.56	1.56	1.56	1.55
65	12.2						1.36	1.52	1.49	1.52	1.52	1.51	1.36	1.55	1.54	1.53	1.55	1.42	1.55	1.53	1.55	1.54
76	12.2						1.28	1.51	1.44	1.51	Testing Discontinued Charge # 69						1.52	1.22	1.52	1.50	1.53	1.51
87	12.2						1.06	1.43	1.04	1.45							1.49	0.97	1.49	1.47	1.50	1.48
91	12.2						0.94	1.35	0.36	1.41							1.48	0.95	1.47	1.44	1.49	1.47
96	12.2						0.99	1.32	0.28	1.40							1.51	1.08	1.51	1.49	1.52	1.50
100	12.2						0.42	0.92	0.22	1.22							1.48	1.04	1.49	1.47	1.48	1.47
105	12.2						0.19	0.42	0.17	0.55							1.45	0.81	1.44	1.39	1.47	1.42
110	12.2						0.31	0.58	0.18	0.95							1.47	0.82	1.45	1.42	1.47	1.44
114	12.2						0.87	0.80	0.34	1.25							1.36	1.25	1.35	1.38	1.42	1.34
121	12.2						0.17	0.32	0.14	0.41							1.40	0.93	1.30	1.32	1.39	1.30
125	12.2						0.86	0.88	0.29	1.13							1.44	1.07	1.35	1.39	1.42	1.30
126	9.5						1.38	1.46	1.47	1.48							1.54	1.45	1.53	1.54	1.53	1.52
131	9.5						1.09	1.28	0.60	1.40							1.52	1.35	1.50	1.51	1.52	1.50
135	9.5						0.81	0.98	0.16	1.28							1.49	1.26	1.47	1.47	1.50	1.47
139	9.5						1.00	1.11	0.37	1.32							1.48	1.28	1.46	1.46	1.49	1.45
145	9.5						1.02	1.13	0.34	1.31							1.50	1.25	1.47	1.46	1.51	1.47
149	9.5						0.87	1.02	0.26	1.18							1.46	1.15	1.44	1.42	1.48	1.46
150	9.5						0.87	1.02	0.26	1.07							1.46	1.15	1.44	1.42	1.49	1.47
152	9.5						0.97	0.95	0.23	1.15							1.35	1.10	1.32	1.33	1.47	1.35
155	9.5						0.19	-0.14	0.15	0.24							1.45	1.17	1.45	1.46	1.51	1.47
157	9.5						1.04	-0.16	0.57	1.19							1.44	*	*	*	*	*
158	9.5						0.95	-2.01	0.41	1.14												

* Not Recorded

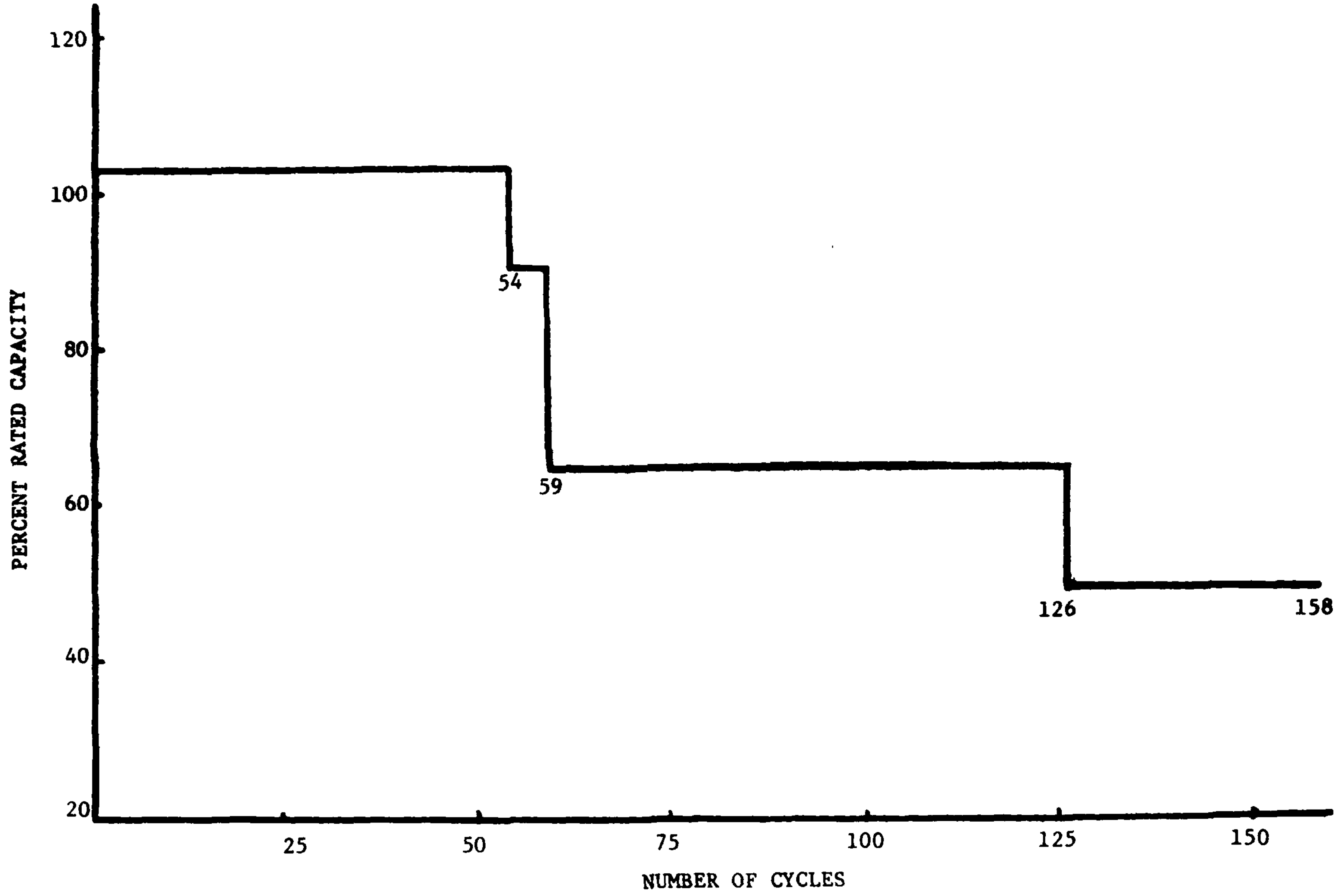

FIGURE 8
DEPTH OF DISCHARGE
DEVELOPMENT CELLS-THIRD SERIES
10.0 AMP DISCHARGE

2.3.3 Cycle Status

Cell performance for the first twenty (20) cycles was essentially the same, however, during cycle 20, some differences in individual cell charge characteristics became evident. Cells 1-5 began reaching high end-of-charge voltages. End-of-charge voltages and end-of-discharge voltages for cycle number 25 are summarized in Table 15.

TABLE 15

THIRD SERIES - CYCLE 25

CELL NO.	END OF CHARGE VOLTAGE	END OF DISCHARGE VOLTAGE
1	1.96	1.50
2	1.92	1.51
3	1.97	1.52
4	1.93	1.51
5	1.92	1.52
6	1.89	1.14
7	1.91	1.52
8	1.91	1.51
9	1.89	1.52
10	1.88	1.51
11	1.90	1.53
12	1.89	1.40
13	1.95	1.52
14	1.95	1.52
15	1.93	1.52
16	1.88	1.52
17	1.88	1.47
18	1.88	1.51
19	1.88	1.48
20	1.88	1.52
21	1.88	1.51

2.3.3 Cycle Status (continued)

Due to equipment limitations all cells in the Third Series were series connected and cycled off the same automatic cycle equipment. Cycle #25 data indicated not all cells were fully charged at the end of charge #25, due to the high voltages obtained in cells 1-5, which limited the charge current. Variances in charging characteristics were attributed to separator variables which subsequently affected internal cell resistance and charging characteristics.

2.0 CELL DEVELOPMENT AND EVALUATION

2.3 Development and Evaluation - Third Series

2.3.3 Cycle Status (continued)

High end of charge voltages for cell numbers 1-5 were not consistent to any particular cell. High voltages varied from cycle-to-cycle in which cell would exhibit the high end-of-charge voltage.

Testing was interrupted during the 29th cycle in order to regroup the cells for continued testing purposes. A conditioning cycle was placed on each cell group. This cycle consisted of charging the cells by cell variable group until they were fully charged, and individually discharging each cell to a cutoff voltage of 1.35 volts. Once the conditioning cycle was concluded, the cells were placed back on the automatic cycle system for charge #30. Two hours and twenty-five minutes into charge testing was suspended because the cells were exhibiting premature high voltages.

2.3.3.1 Test Regrouping

Further testing of the cells was done by variable groups. Regrouping of the cells is described as follows:

Cells 1-5: Testing was suspended due to limited equipment availability. Data, at the suspension of testing did not indicate cell performance for this group of cells (RAI nickel coated separators) was

2.0 CELL DEVELOPMENT AND EVALUATION

2.3 Development and Evaluation - Third Series

2.3.3 Cycle Status (continued)

2.3.3.1 Test Regrouping

significantly improved over other cells in the Third Series. In fact, these cells were difficult to charge because of premature high voltage.

Cells 6-9, 10-12 13-15 — The cells were cycled as a battery on the automatic cycle test equipment since these cells ran compatible with each other.

Cells 16-21 — The cells were cycled as a battery on separate cycle equipment. The primary reason for testing this group of cells is to determine if copper grid and copper tab material can successfully be utilized as a replacement for silver grid and silver tabs in the negative electrodes.

2.3.3.2 Suspension of Testing

Testing was suspended on cells # 10-12 (2 Celgard 3400) and cells # 13-15 (2 Celgard 3400/Cellophane) during cycle # 69. At this time, it was becoming difficult to charge cells # 6-15 as a battery. It was more desirable to continue testing cells # 6-9 (4 Celgard 3400) because the separator system is not degradable in the presence of electrolyte. Final test suspension of the Third Series testing was done on the 158th cycle.

2.0 CELL DEVELOPMENT AND EVALUATION

2.3 Development & Evaluation - Third Series

2.3.4 Third Series Tests Results

Final results for the Third Series Development Test Cells are presented as follows:

RAI Separation (cells 1-5)

RAI nickelized separators did not cycle satisfactorily. Cells incorporating the separators reached premature high charge voltages. Originally, cells #1-5 were scheduled to be constructed with Celgard K317 (nickel coated), however, this material was not available at the time of the Third Series construction. Nickel coated separators in theory, should aid in decreasing zinc dendrite numbers by oxidizing the dendrites at the separation site before the dendrites accumulate, penetrate separation barriers, and short to the nickel electrodes.

Four layers of 3400 Celgard (cells 6-9)

Discharge performance for cells containing Celgard as the only barrier separation was poorer than that of cells incorporating cellophane along with the Celgard. Exclusive use of Celgard yields an extremely thin, nondegradeable, cell pack. However, the tradeoff is reduced cell wettability. Post morten examination of cells 6-9 revealed dry areas in the cell pack.

2.0 CELL DEVELOPMENT AND EVALUATION

2.3 Development & Evaluation - Third Series

2.3.4 Third Series Tests Results

Two layers of 3400 Celgard (cells 10-12)

Cells 10-12 were orginally constructed to serve as control cells for cells # 1-5 (RAI separation) since the two groups of cells differed only by the addition of the RAI separation. Testing was suspended on cells 10-12 for two reasons; First, testing was discontinued on the RAI separation cells which was no longer necessary to maintain a control, and second, available cycle equipment was used for cells containing four layers of Celgard.

Two Layers 3400 Celgard/One Layer Cellophane (cells 13-15)

Testing was discontinued on these cells at cycle number 69. At this time cell performance was good. Testing was discontinued so cycle equipment would be available for cells containing the four layers of Celgard 3400.

Copper Grid-Negative (cells 16-21)

Based upon the Third Series data, cells incorporating copper grid and tabs in the zinc electrode cycled as well as cells containing silver grid and silver tabs in the zinc electrode. Recent fluctuationsin silver prices made it desirable to eliminate silver from the nickel-zinc system, particularly in future applications.

3.0 MAR-5013 BATTERY

The potential nickel-zinc battery to be used in the place of existing lead-acid batteries for the BQM-34A RPV has been assigned Eagle-Picher battery number MAR-5013. General characteristics of this battery are listed in Table 16. Figure 9 is a picture of a MAR-5013 battery.

TABLE 16

MAR-5013 BATTERY DESIGN

NUMBER OF CELLS:	18
BATTERY WEIGHT:	27 lbs. (including container)
SIZE:	6.40" X 4.75" X 11.75"
NOMINAL VOLTAGE:	28 Volts
MIDPOINT VOLTAGE AT 15.0 AMPS	28.5 V - Electrochemical 29.0 V - Conventional
MIDPOINT VOLTAGE AT 45.0 AMPS	26.0 V - Electrochemical 27.0 V - Conventional
OPEN CIRCUIT VOLTAGE, CHARGED:	32 V - 33.5 V
OPEN CIRCUIT VOLTAGE DISCHARGED:	29.5 V - 31 V
CELL CASE MATERIAL:	SAN, Plastic, Transparent to Check Electrolyte level
SPECIAL FEATURES:	Battery Hold-Downs Fastened to battery top Electrolyte Reservoir in cell cover to avoid electrolyte spillage from inverted battery.

FIGURE 9

MAR-5013 Battery

3.0 MAR-5013 BATTERY

3.1 Battery Components

Previous experimental cell testing in the First and Second Series of development test cells provided the background data for the selection of the first initial MAR-5013 batteries. Selection of individual cell components is summarized as follows:

3.1.1 Separator

The separator system chosen for the initial MAR-5013 batteries was as follows:

+, pellon, celgard 3400, cellophane, celgard 3400, cellophane, celgard 3400, cellophane, pellon,-

Based upon experimental cell testing at the time of separator selection, the 3 celgard/3 cellophane was the most reliable with respect to cell cycle life.

3.1.2 Zinc Electrode

Based upon experimental cell data, the standard Eagle-Picher zinc electrode with a latex binder was selected. No significant advantages were demonstrated for any of the zinc electrode composition variables.

3.1.3 Nickel Electrode

Nickel electrodes were doubled in the MAR-5013 cell design in order to provide additional capacity. The BQM-34A permanently mounted battery box contains a heater so the reduction in cell surface area of the doubled electrodes will not be critical for low-temperature performance. Two types

3.0 MAR-5013 BATTERY

3.1 Battery Components

3.1.3 Nickel Electrode (continued)

of nickel electrodes have been utilized in the RPV program. The two types are described as follows:

Electrochemical impregnation plates were selected for the first seven (7) MAR-5013 batteries. There were two reasons for the selection of this type nickel electrode. The electrochemical impregnation methods have an advantage over the conventional vacuum impregnated electrode in the areas of dimensional stability and ultimate reduced manufacturing cost.

Seventeen (17) were constructed with conventional vacuum impregnated nickel electrodes. Data from the first seven batteries (Electrochemical nickel electrodes) as discussed in Section 1, Paragraph 3.4 indicated battery capacity was not comparable to batteries or test cells constructed with conventional impregnated vacuum nickel electrodes.

3.2 Cell Design

Table 17 describes the cell characteristics for the first seven (7) MAR-5013 batteries. A MAR-5013 cell is pictured in Figure 10.

FIGURE 10
MAR-5013 CELL

TABLE 17
MAR-5013 CELL DESIGN(Electrochemical)

CONFIGURATION: 8 Double Pos/9 Neg.

ELECTRODE SIZE: 2.115" x 4.70"

POSITIVE ACTIVE MATERIAL LOADING: .65 gm/in^2
(single electrode)

TYPE POSITIVE ELECTRODE: Electrochemical Impregnation on .025"
Slurry Sinter

POSITIVE THEORETICAL CAPACITY: 28.3 AH

POSITIVE TAB TO TERMINAL CONNECTION: Spotweld

NEGATIVE ACTIVE MATERIAL LOADING: 1.9 gm/in^2

NEGATIVE ELECTRODE THICKNESS: .042"

NEGATIVE ELECTRODE DENSITY; 46 gm/in^3

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY: 3.33/1

SEPARATOR: Pellon, 3 Celgard/3 Cellophane, Pellon

CELL SURFACE AREA: 150.2 in^2

ELECTROLYTE: 31% KOH, No additives

3.0 MAR-5013 BATTERY

3.2 Cell Design (continued)

Table 18 describes the cell characteristics of the first nine (9) conventional MAR-5013 batteries. Table 19 describes cell characteristics for the final seven (7) MAR-5013 batteries constructed. The final seven (7) batteries incorporated copper grid and tabs in the negatives instead of silver grid and tabs.

TABLE 18

MAR-5013 CELL DESIGN (conventional)

CONFIGURATION: 6 Double Pos-2 Outside Single/7 Neg.

ELECTRODE SIZE: 2.115" x 4.70"

POSITIVE ACTIVE MATERIAL LOADING: .80 gm/in^2 (single electrode)

TYPE POSITIVE ELECTRODE: Conventional Impregnation/Dry Sinter

POSITIVE THEORETICAL CAPACITY: 30.5AH

POSITIVE TAB TO TERMINAL CONNECTION: Spotweld

NEGATIVE ELECTRODE THICKNESS: .042"

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY: 2.70/1

SEPARATOR: Pellon, 3 Celgard/3 Cellophane, Pellon

CELL SURFACE AREA: 122 in^2

ELECTROLYTE: 31% KOH, No additives

TABLE 19

MAR-5013 CELL DESIGN (conventional)

CONFIGURATION: 8 Double Pos/9 Neg

ELECTRODE SIZE: 2.115" x 4.70"

POSITIVE ACTIVE MATERIAL LOADING: 0.80 gm/in^2 (single electrode)

TYPE POSITIVE ELECTRODE: Conventional Impregnation
Dry Sinter

POSITIVE THEORETICAL CAPACITY: 34.7 AH

POSITIVE TAB TO TERMINAL CONNECTION: Spotweld negative electrode

NEGATIVE ELECTRODE GRID AND TAB: Copper

NEGATIVE ACTIVE MATERIAL LOADING: 2.10 gm/in^2, no additives

NEGATIVE ELECTRODE THICKNESS: .044"

NEGATIVE ELECTRODE DENSITY: 49 gm/in^3

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY: 2.99/1

SEPARATOR: Pellon, 3 Celgard/2 Cellophane, Pellon

CELL SURFACE AREA: 150.2 in^2

ELECTROLYTE: 31% KOH, No additives

3.0 MAR-5013 BATTERY

3.3 Manufacture of MAR-5013

A total of twenty-four MAR-5013 batteries were manufactured. Batteries were constructed for Calendar and Cycle Life Testing, Qualification Testing, and actual BQM-34A Flight Testing. Table 20 is a breakdown of battery test types.

TABLE 20

MAR-5013 BATTERY MANUFACTURE

TYPE BATTERY	NUMBER MANUFACTURED
Calendar and Cycle Life Testing	3
Qualification Testing	6
Flight Testing	15

3.4 Calendar and Cycle Life Batteries

The three (3) Calendar and Cycle Life batteries were constructed with Electrochemical nickel electrodes (see Table 17)

The test objectives for the Calendar and Cycle life batteries were:

1) Demonstrate calendar life under actual rate of cycling

2) Optimize the procedure for electrical conditioning

3.0 MAR-5013 BATTERY

3.4. Calendar and Cycle Life Batteries

3.4.1 Calendar and Cycle Life Schedule

The initial calendar and cycle life schedule was as follows:

Battery 1-Receive one cycle per week (indefinite period). The battery will stand in the charged condition and will not be top charged before receiving a 14 amp discharge.

Battery 2-Receive one cycle per week. (indefinite period). The battery will stand in the discharged condition and will receive a routine charge and 14 amp discharge.

Battery 3-(First two tests)

1) The battery will stand in the charged condition for one month and will be top charged before receiving a 45 amp discharge.

2) The battery will stand in the charged condition for 2 months and will be top charged before receiving a 15 amp discharge. Once discharged, the battery will be routinely charged and discharged at 15 amps.

The batteries were formed at 150 percent theoretical capacity at a constant current rate of five (5) amps. Formation discharges were conducted at 14-15 Amps until the first cell in each battery reached a cut-off voltage of 1.35 volts. Routine charging of the Calendar and Cycle life batteries consisted of a five (5) amp constant current charge until battery voltage reached 34.4 volts. Once this voltage was reached, charging was completed by a five (5) amp limited constant

3.0 MAR-5013 BATTERY

3.4 Calendar and Cycle Life Batteries

3.4.1 Calendar and Cycle Life Schedule (continued)

potential charge until input was 105-110% of the previous discharge. Routine discharging of the batteries was conducted at 14-15 Amps constant potential and later changed to 14 Amps constant current when equipment became available.

3.4.2 Preliminary Investigations

Preliminary storage performance tests and temperature performance investigations were conducted on the MAR-5013 batteries for characterization purposes. These tests were not required for the batteries. Specific test are presented as follows:

3.4.2.1 Temperature Tests

Battery performance at two different discharge rates(14 amps and 45 amps) and at various temperatures was investigated. Cold temperature investigations did not employ the use of a battery heater. All testing was conducted on the same calendar and cycle life battery (Battery 2). Test regimes included:

1) 14 Amps - 75°F (Figure 11)
2) 14 Amps - 27°F (Figure 12)
3) 14 Amps - 5°F (Figure 13)
4) 45 Amps - 72°F (Figure 14)
5) 45 Amps - 35°F (Figure 15)

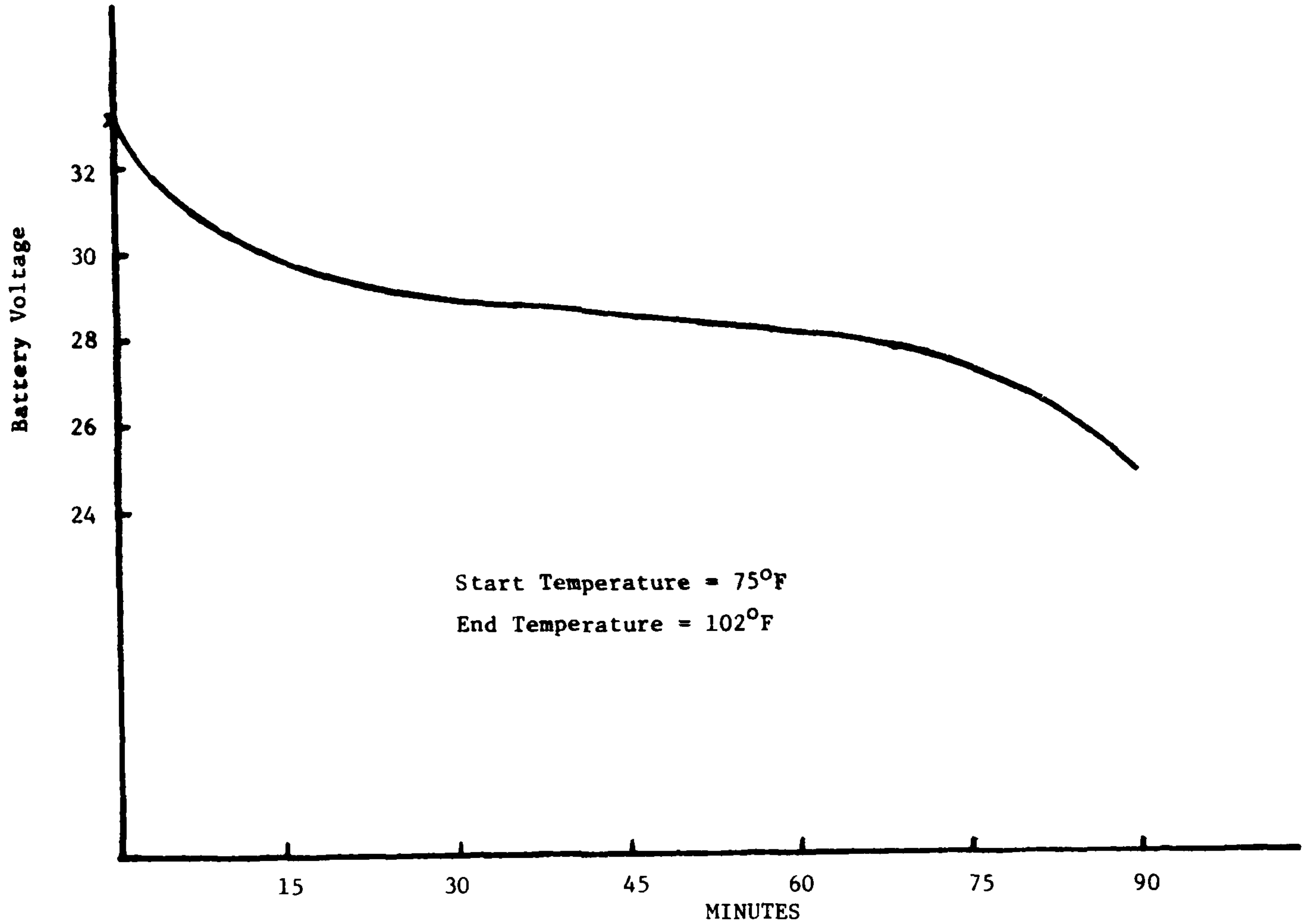

Figure 11

MAR-5013

75°F - 15 Amps

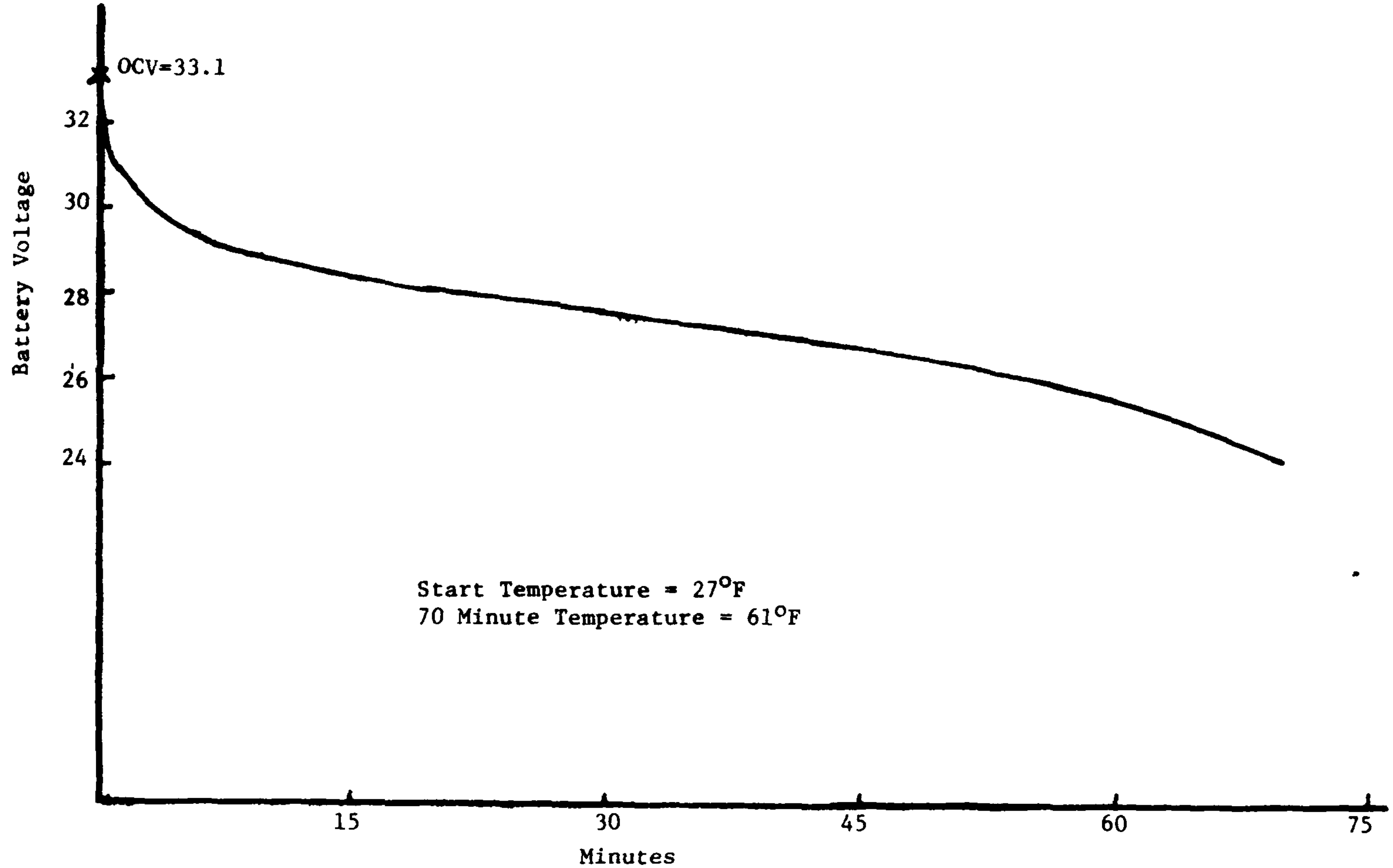

Figure 12

MAR-5013
27°F - 14 Amps

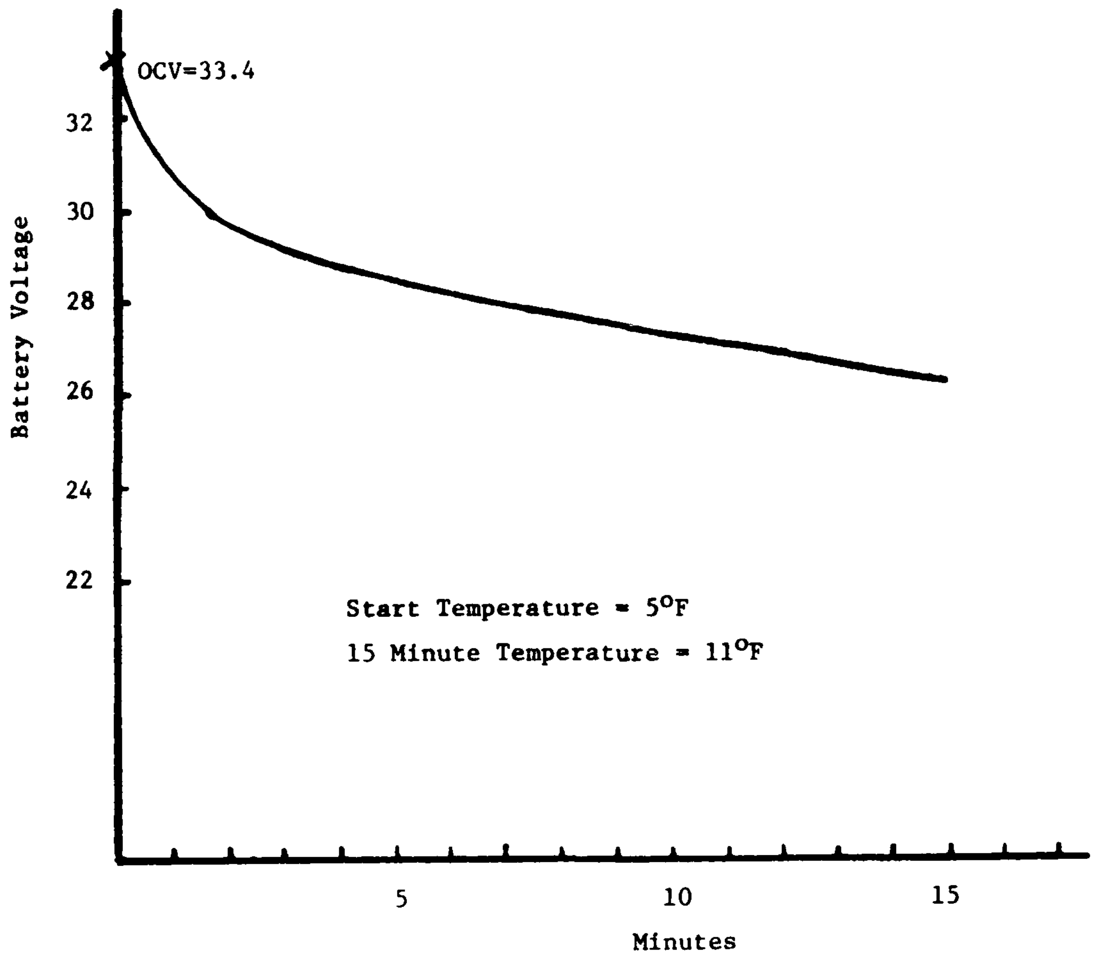

Figure 13

MAR-5013

5°F - 14 Amps

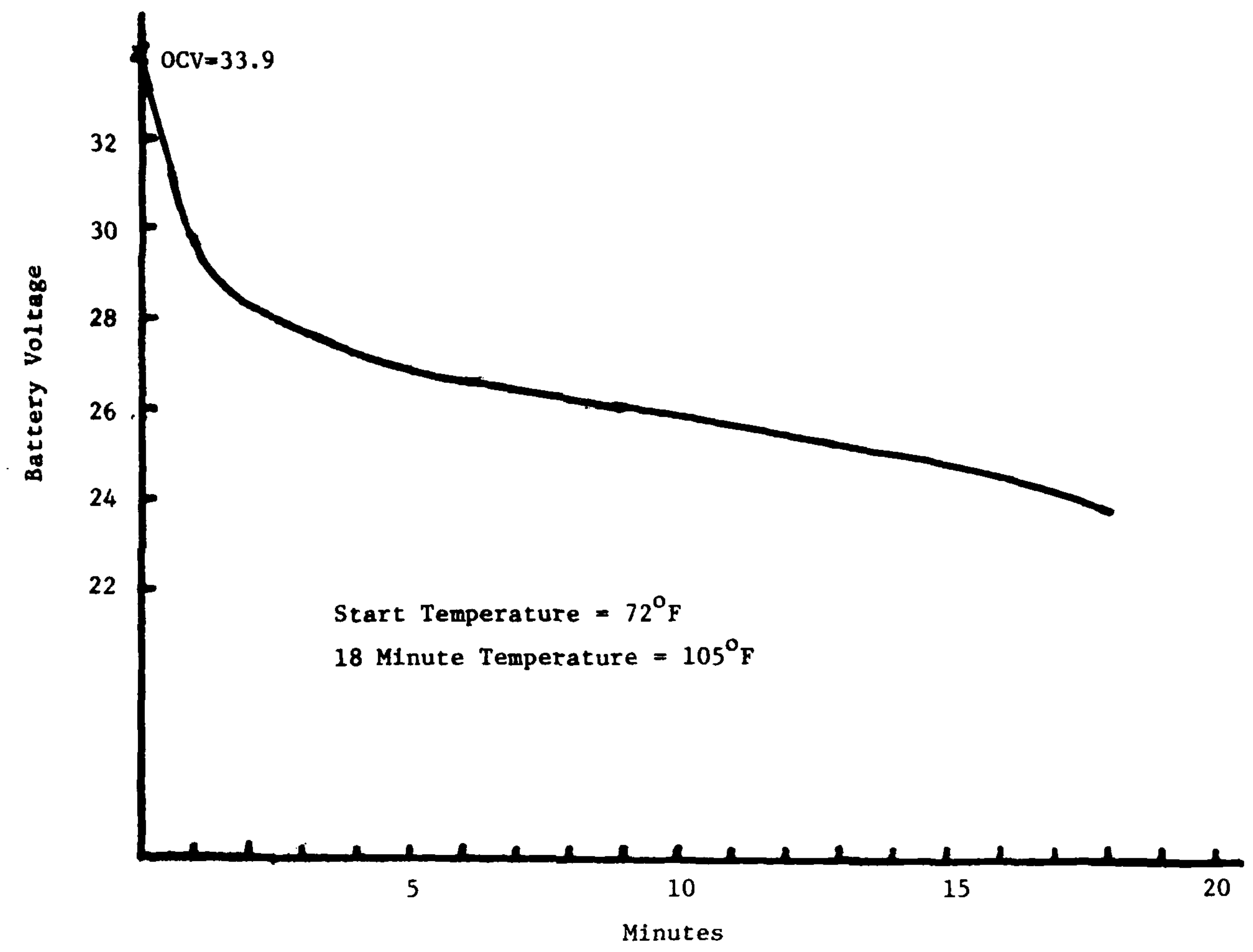

Figure 14

MAR-5013
72°F - 45 Amps

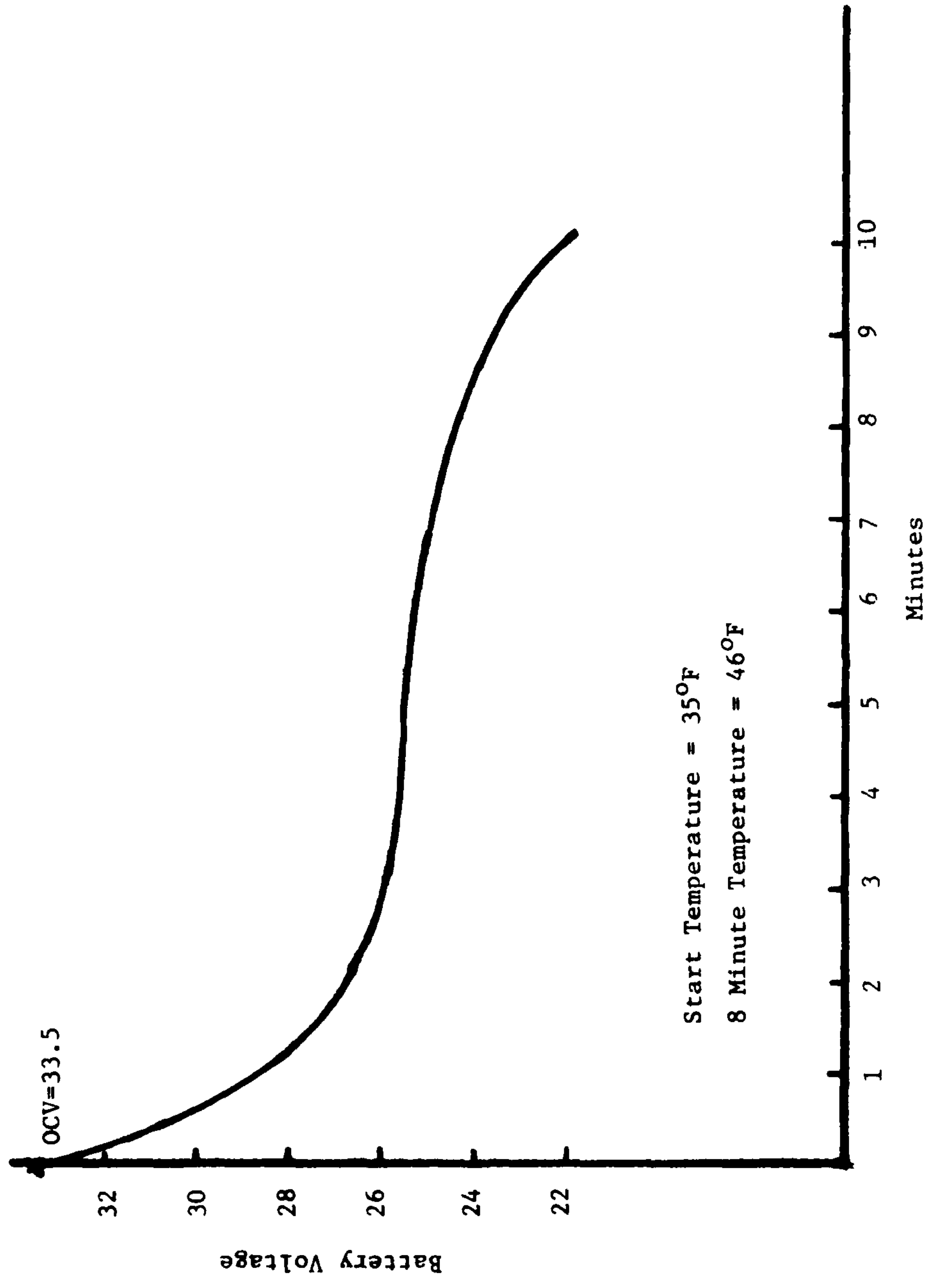

Figure 15

MAR-5013
$35^{o}F$ - 45 Amps

3.0 MAR-5013 BATTERY

3.4 Calendar and Cycle Life Batteries

3.4.2. Preliminary Investigations

3.4.2.1 Temperature Tests (continued)

Temperatures recorded on the graphs (Figure 11-15) were taken at the center of the battery, between the two rows of cells.

Test results indicated the MAR-5013 will deliver greater than 12.5 AH (the existing lead acid minimum capacity) at 14 Amp-75°F, 14 Amps-27°F, 45 Amps 75°F. The 12.5 AH capacity cannot be met at 14 Amps-5°F and 45 Amps 35°F without the aid of a battery heater.

3.4.2.2 Storage Testing

Preliminary storage data was generated for a one week and three week charged stand. The data is summarized in Table 21.

TABLE 21

MAR-5013 STORAGE TEST

DISCHARGE	OCV	AH	RATE
Initial	34.1	20.0	Constant Resistance 11.8 Amps at 1 hour
1 Week	31.8	18.3	Constant Resistance 11.6 Amps at 1 hour
3 Weeks	31.3	16.1	Constant Current 14 Amps

Figure 16 graphically represents the discharges for each storage test.

Initial data has indicated the MAR-5013 battery may be used without a top charge after a one week stand. The fresh battery yielded 90% of rated capacity.

Periods of three week stands yielded 81% rated capacity and should receive a top charge before using.

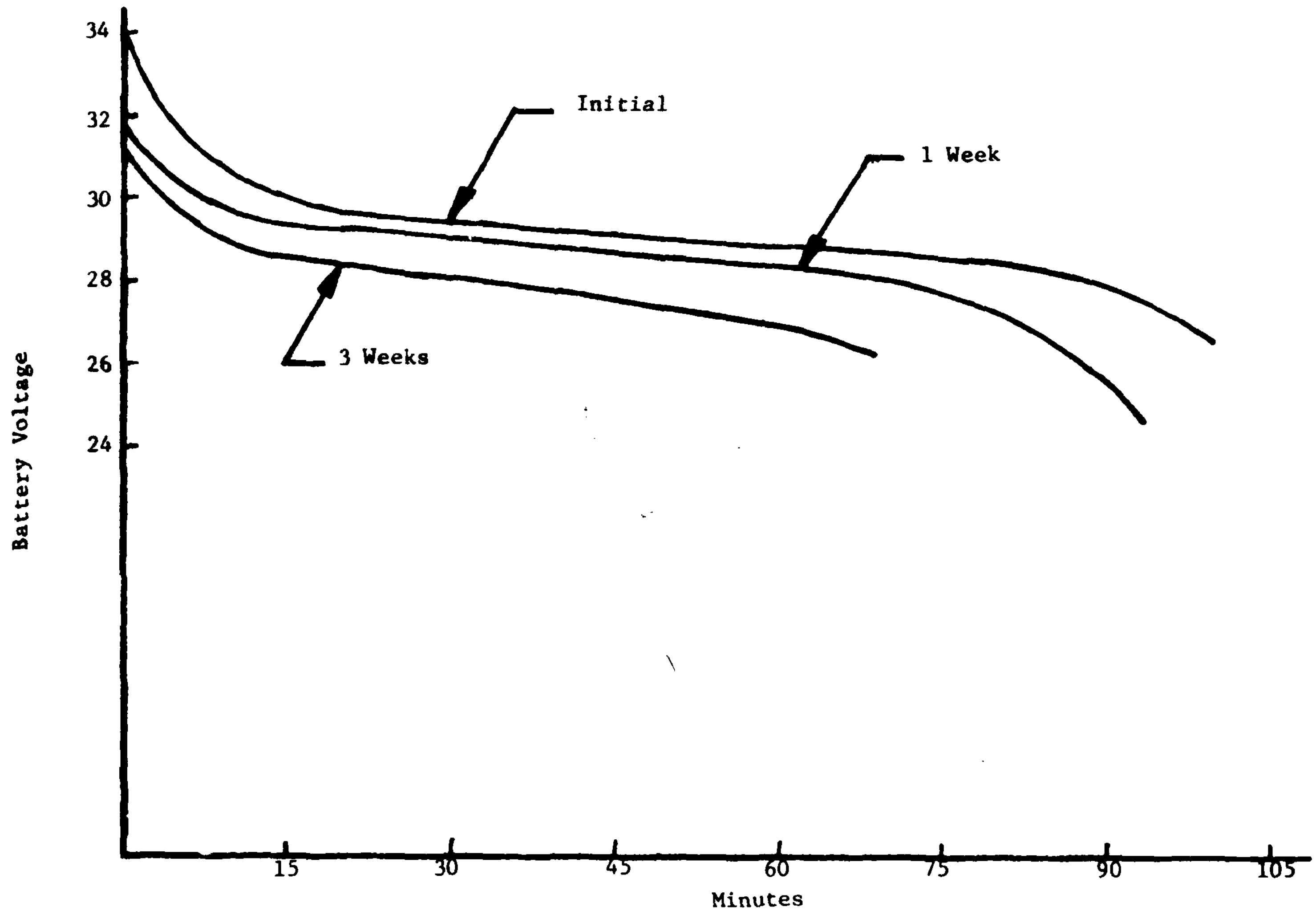

FIGURE 16

MAR-5013 STORAGE TEST
CALENDAR AND CYCLE LIFE

3.0 MAR-5013 BATTERY

3.4 Calendar and Cycle Life Batteries

3.4.3 Calendar and Cycle Life Test Results

At the end of this reporting period, the Calendar and Cycle Life Batteries are 21 months old (activated age). Test results for each battery are discussed individually. Through-out most of the testing, the Calendar and Cycle Life Batteries were discharged until one cell in the battery reached 1.35 volts. Final battery test cut-off voltage for the eighteen (18) cell MAR-5013 was 24.3 volts.

From the onset of testing, battery capacity for the MAR-5013 Calendar and Cycle batteries was never acceptable.

The MAR-5013 battery was designed to deliver initially around 20 AH. This battery performance was not realized in batteries constructed with electrochemical nickel electrodes; however, it was later demonstrated in batteries constructed with conventional process nickel electrodes (refer to section 3.5). Test data also indicated that capacity fade was accelerated with the electrochemical nickel electrodes. Testing was continued with the Calendar and Cycle Life Batteries even though capacity performance was poor in order to gain additional battery testing experience and information on calendar life. Prior to the Calendar and Cycle Life Batteries, most cycle testing on the nickel-zinc system had been done on a relatively small scale with a few test cells rather than multicell batteries.

3.4.3.1 Calendar and Cycle Life - Battery 1

Battery 1 received a total of 67 cycles at the conclusion of testing. Discharge results for the first 22 cycles are individually listed in Table 22. Randomly selected cycle results for Cycles 23-67 are also listed in the table.

As indicated in Table 22, the battery exhibited capacity fading early in cycle-life testing. Testing the condition of one week charged storage between discharge was discontinued after Cycle 21 because data was not relevant in view of fading battery capacity. Discharges were consistently limited by one cell in the battery reaching 1.35 volts early while voltages for the other cells ranged from 1.47-1.51 volts. Figure 17 is a graph of discharges 8, 15 and 22.

Additional charge-discharge cycles accumulated on the battery after cycle 21 were ususally conducted in one day. Testing for cycles 23-43 was conducted at 10-15 amps constant resistance until one cell in

TABLE 22

MAR-5013 CALENDAR AND CYCLE LIFE

Battery 1

Cycle Number	Days Between Charge/Discharge	Discharge Rate (amps)	Discharge Capacity (AH)
1	0	11.8A@1 hr@cr*	19.0 (25.5V)
2	0	11.8A@1 hr@cr	19.9 (26.0V)
3	0	11.8A@1 hr@cr	20.9 (25.9V)
4	0	11.7A@1 hr@cr	19.8 (27.0V)
5	21	14A/cc**	16.1 (26.2V)
6	14	14A/cc	15.9 (26.6V)
	Battery subjected to week charge-stand testing		
7	6	14A/cc	17.5 (26.3V)
8	7		16.3 (26.1V)
9	7		16.8 (25.6V)
10	7		14.7 (26.3V)
11	7		15.6 (26.1V)
12	7		14.5 (26.2V)
13	7		14.0 (26.4V)
14	7		13.1 (26.3V)
15	7		12.1 (26.5V)
16	0		14.0
17	0		15.2 (26.1V)
18	6		16.1
19	7		12.6
20	7		11.7
21	6		12.8
22	0	14A/cc	12.1 (26.0V)
23		13.6A@63min@cr	15.5
24		13.6A@59min@cr	14.4
25		14.3A@58min@cr	14.3
30		11.9A@1 hr	13.8
35		12.1A@34min	6.8
40		11.7A@47min	10.1
45		11.1A@52min	10.4
50		45 min disc@11.2A final	9.1
55		40 min disc@11.2A final	8.2
60***		10.1A@1 hr	12.5 (24.6V)
65		15A/cc	6.8 (24.3V)
67	0	15A/cc	7.1 (24.3V)

* cr = constant resistance

** cc = constant current

*** Last time delivered 12.5 AH at or above 24.3 volts

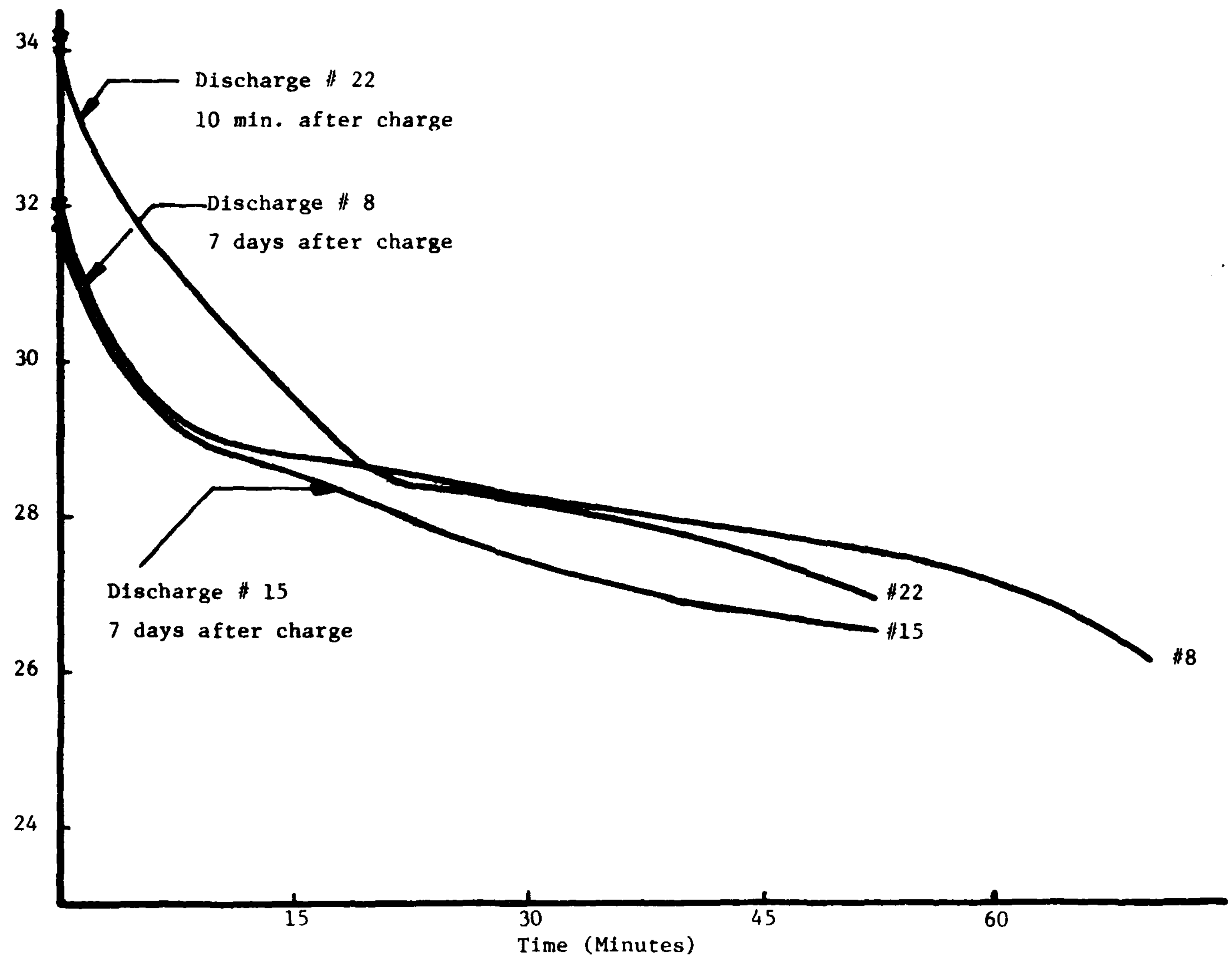

FIGURE 17

CALENDAR AND CYCLE LIFE - BATTERY 1
75°F - 14.0 Amps

3.0 MAR-5013 BATTERY

3.4 Calendar and Cycle Life Batteries

3.4.3 Calendar and Cycle Life Test Results

3.4.3.1 Calendar and Cycle Life - Battery 1 (continued)

the battery reached 1.35 volts. Battery voltage remained above the 24.3 volt battery cut-off. Discharges 45-53 were conducted for 45 minutes and discharges 54-55 were conducted for 40 minutes. Discharge 60 was the last time the battery would deliver 12.5 AH (the existing lead-acid service capacity) at battery cut-off voltage.

3.4.3.2 Calendar and Cycle Life - Battery 2

Battery 2 received a total of 74 cycles at the conclusion of testing. Capacity fading in Battery 2 was not as dramatic as Battery 1. Battery 2 was used for the preliminary storage and temperature investigations previously discuseed in paragraph 3.4.2. Testing the condition of discharged storage before charge (cycles 11-22) was also discontineud because of fading battery capacity. Discharge results for the battery are summarized in Table 23.

Testing for cycles 23-47 was conducted at 10-15 amps constant rssistance until one cell in the battery reached 1.35 volts. Testing during cycles 48-69 was conducted for 45 minutes except for cycle 60. Discharge 60 was conducted to determine if the battery would still deliver 12.5 AH at or above 24.3 volts.

TABLE 23

MAR-5013 CALENDAR AND CYCLE LIFE

Battery 2

Cycle Number		Days Between Charge/Discharge	Discharge Rate (amp)	Discharge Capacity
1		0	11.9A@1 hr@cr*	21.1 (25.8V)
2		0	11.9A@1 hr@cr	21.1 (25.8V)
4		0	11.8A@1 hr@cr	20.0 (26.2V)
5		7	11.5A@65 min cr	18.3
6	38°F	0	45 amps/cc**	6.0
7	5°F	0	14A/cc	3.5
8	72°F	0	45A/cc	13.5
9	27°F	1	14A/cc	16.3
Battery subjected to week discharge stand storage before charge				
10		13	14A/cc	16.3
11		1		18.8
12		0		19.8
13		0		18.7
14		0		17.7 (24.3V)
15		3		18.7 (25.9V)
16		0		18.7 (26.3V)
17		1		15.4 (27.1V)
18		0		19.1
19		3		14.0
20		0		18.0
21		1		19.8
22		1	14A/cc	19.8
25		0	12.3A@cr@1 hr	18.3 (25.5V)
29		0	13.4A@cr@1 hr	19.3 (25.8V)
35		0	12.3A@cr@67 min	18.2
40		0	12.1A@cr@52 min	13.0
45		0	11.9A@cr@65 min	13.8
50		0	45 min cr disc@12.3A final	9.7
56		1	45 min cr disc@12.1A final	9.7
60			11.9A@cr@1 hr	12.8 (27.2V)
65			45 min cr disc/12.8A final	9.6 (27.6V)
70			15A/cc	11.8 (24.3V)
74		0	3A/cc	12.9 (24.3V)

* cr = constant resistance
** cc = constant current

3.0 MAR-5013 BATTERY

3.4 Calendar and Cycle Life Batteries

3.4.3 Calendar and Cycle Life Test Results

3.4.3.2 Calendar and Cycle Life - Battery 2 (continued)

The battery would not deliver 12.5 amps above 24.3 volts during cycle 70. A capacity of 12.9 AH to battery cut-off voltage at an 8 amp rate was obtained in discharge 74.

3.4.3.3 Calendar and Cycle Life - Battery 3

Battery 3 received a total of 152 cycles at the conclusion of testing. Discharge results for the battery are listed in Table 24. Testing for the first 57 cycles was normally conducted until one cell in the battery reached 1.35 volts. Cycles 13 and 14 were charge storage tests. For Cycle 13 testing, the battery received a normal charge and was then stored for one month at room ambient conditions. After storage, the battery was top charged (3AH input) before being subjected to a 45 amp discharge. Cycle 15 represents a 15 amp discharge after a charged storage of two months. The battery was top charged (4.4 AH input) before discharge.

A capacity check was performed during discharge 58 to determine battery capacity at the 24.3 volt cut-off. The battery delivered 16.6 AH.

Cycles 59-152 were conducted on an automatic cycle system. Discharge was conducted at 8.0 amps for 1 hour, 12 minutes (9.6 AH).

TABLE 24

MAR-5013 CALENDAR AND CYCLE LIFE

Battery 3

Cycle Number	Days Between Charge/Discharge	Discharge Rate (amp)	Capacity Removed (AH)
1	0	*cr/11.8 at 1 hr	19.9 (26.9V)
2	0	cr/11.8 at 1 hr	20.1 (27.5V)
3	0	cr/11.7 at 1 hr	19.3 (27.6V)
4	0	cr/11.7 at 1 hr	19.6 (27.2V)
6	0	14A/cc**	17.5 (24.9V)
7	0	14A/cc	18.0 (27.0V)
8	0	14A/cc	17.7 (25.9V)
10	1	14A/cc	19.1 (25.2V)
12	0	14A/cc	18.7 (26.0V)
13	One month storage - top charged	45A/cc	13.5
14	Two month storage - top charged	14A/cc	17.5
17	0	14A/cc	17.5 (26.1V)
21	1	cr/11.6 at 1 hr	17.0
25	1	cr/12.3 at 1 hr	17.0
30	1	cr/12.2 at 1 hr	16.1
35	0	cr/12.2 at 1 hr	12.8
42	0	1 hr disch/11.9 final	12.5
45	0	1 hr disch/11.9 final	12.8
50	0	1 hr disch/11.4 at 1 hr	12.8
55	0	1 hr disch/11.2 at 1 hr	12.2
58		cr/11.6 at 1 hr	16.6 (24.3V)
	Battery placed on automatic cycler at 8.0 amp discharge for 1.2 hours		
59	0	8.0	9.6 (28.8V)
68			(28.2V)
80			(28.0V)
91			(27.7V)
107			(27.8V)
120			(27.6V)
126			(27.2V)
135			(25.9V)
141			(25.0V)
145			(25.5V)
149			(24.9V)
150			(24.0V)
152	0	8.0	9.6 (23.8V)

* cr = constant resistance
** cc = constant current

3.0 MAR-5013 BATTERY

3.5 Qualification Batteries

A total of six (6) MAR-5013 batteries were constructed for qualification testing purposes. The two (2) cycle life batteries were constructed with conventionally impregnated nickel electrodes (see Table 18). The remaining four (4) batteries contained the electrochemical nickel electrodes (See Table 17). The qualification test matrix the batteries were subjected to is described in Table 25. Qualification testing was conducted in accordance with Eagle-Picher's QTP-257 and MIL-STD-810. Battery test orientation is shown in Figure 18.

TABLE 25

MAR-5013 QUALIFICATION TESTING

NON OPERATING TEST	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	6
Humidity	Procedure II, Method 507 MIL-STD-810			x			
Temperature Shock	Procedure I, Method 503	x					
Sand & Dust	Procedure I, Method 510 MIL-STD-810						
Salt Fog	Procedure I, Method 509 MIL-STD-810						x
Fungus	Procedure I, Method 508.1 MIL-STD-810						x

3.0 MAR-5013 BATTERY

3.5 Qualification Batteries

TABLE 25 (continued)

MAR-5013 QUALIFICATION TESTING

OPERATING TEST	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	6
Mechanical Shock	Procedure I, Method 516 MIL-STD-810. The shock test shall be a half sine wave with a 15g peak and a duration of .011 seconds.	x					
Vibration	Battery shall perform normally during vibration of 10 to 500 Hz with input of .036 inch double amplitude or 10g whichever is the limiting factor. Vibration shall be applied in the normal upright position for 30 minutes.	x	x				x
Attitude	Battery discharge performance shall not be affected by an angle of 60^{o} minimum from either horizontal axis.	x	x				
Altitude	Battery discharge shall not be affected by operation at altitudes up to 60,000 ft., and climb to or dive from this altitude in a period of 15 minutes.	x					
Acceleration	The battery shall perform normally during accelerations of 7.5g along the +X,-X,+Y,-Y, and +Z axis for 1.0 sec.	x					

3.0 MAR-5013 BATTERY

3.5 Qualification Batteries

TABLE 25 (continued)

MAR-5013 QUALIFICATION TESTING

OPERATING TEST	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	6
Cycle Life, 15A	The battery shall achieve 100 cycles when cycled at a 15 Amp rate of discharge to an 80% depth of discharge (DOD). Battery voltage shall be 24.3 volts or greater at end of discharge.				x		
Cycle Life, 45A	The battery shall achieve 50 cycles when cycled at a 45 amp rate of discharge to a 50% DOD. Battery voltage shall be 24.3 volts or greater at end of discharge.					x	

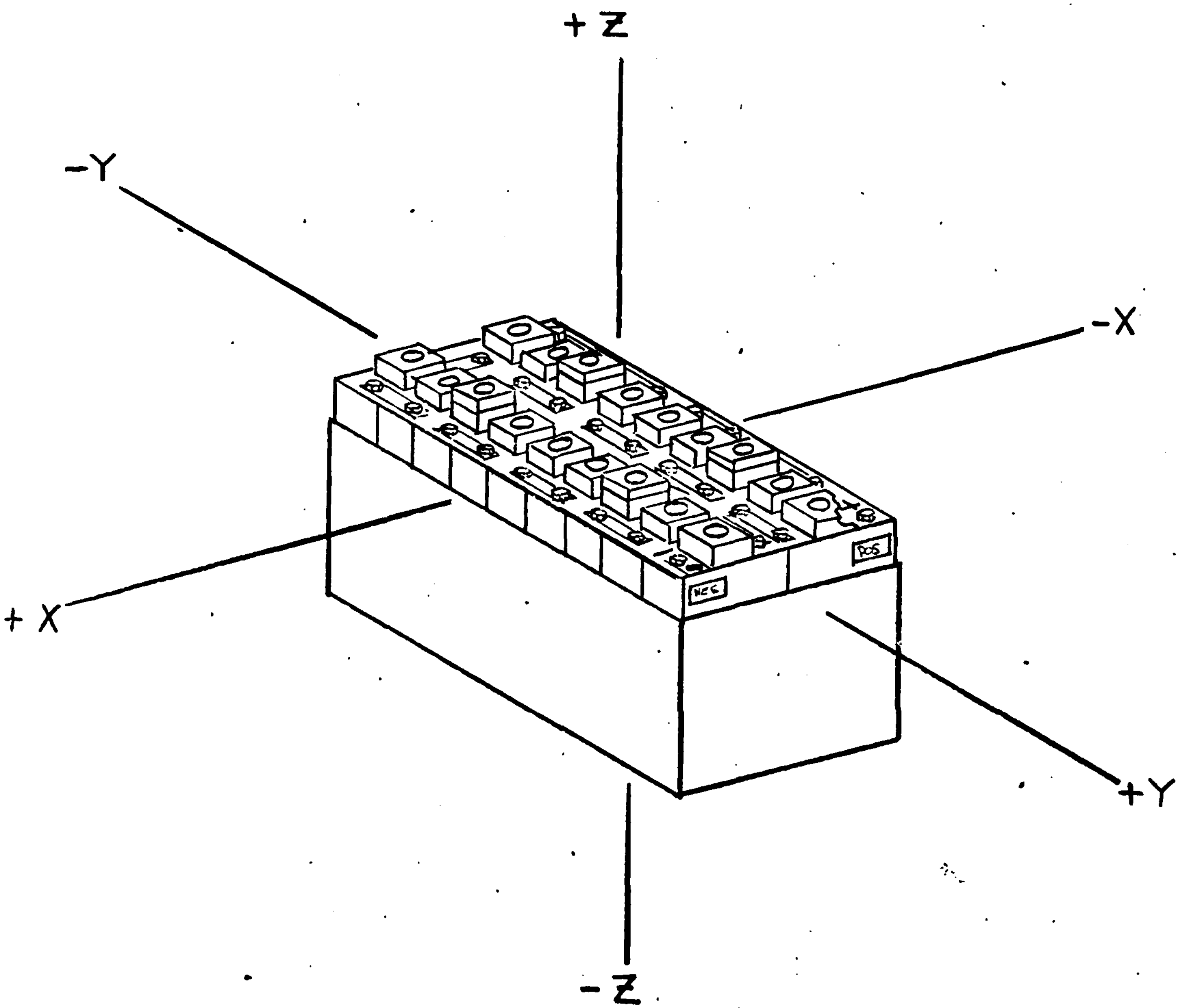

FIGURE 18
MAR-5013
BATTERY ORIENTATION

3.5 Qualification Batteries

3.5.1 Non-Operating Tests

Battery testing for the non-operating portion of qualification testing was conducted with the MAR-5013 installed in the BQM-34A battery box. Figure 19 shows the BQM-34A battery box (cover removed) with an installed MAR-5013 battery. The non-operating test results are individually described.

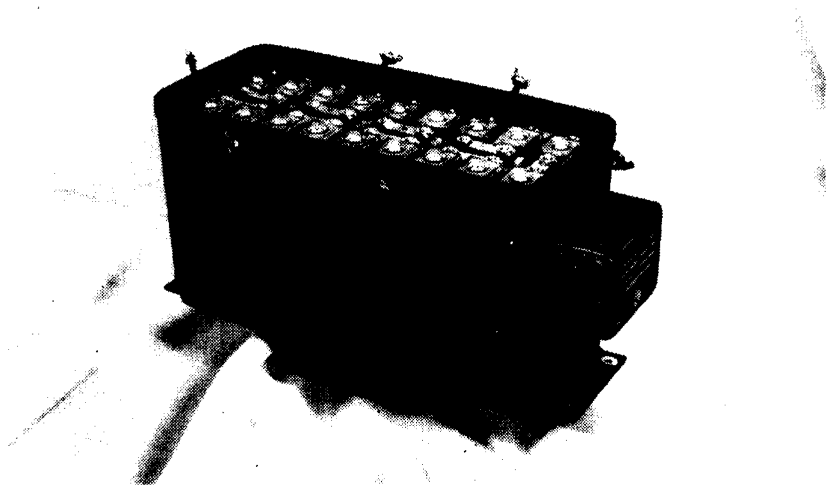

FIGURE 19

MAR-5013 BATTERY IN BQM-34A BATTERY BOX

3.5.1.1 Humidity

Humidity testing was successfully completed on Test Specimen 3 on 6 June 1980. At the conclusion of testing, no signs of physical damage, mechanical damage, or corrosion were evidenced.

3.5.1.2 Temperature Shock

Test specimen 1 was successfully subjected to temperature shock testing on 6 February 1980 in the discharged condition. Open cirucit voltages at the onset and conclusion of testing did not differ significantly with respect to the temperature shock test regime.

Visual examination of the battery in the BQM-34A battery box (cover removed) at the conclusion of testing revealed condensation on the battery top and evidence of crystallized electrolyte around the cell vent plug areas. Condensation and cell venting was the result of going from 160^{o}F to -70^{o}F throughout the duration of the test rather than cracked cell cases. Additionally, the vent port on the BQM-34A battery box was not plugged which made condensation more likely to form on the battery top.

Examination of the battery once it had been removed from the BQM-34A battery box did not reveal

3.5.1.2 Temperature Shock

any signs of physical or mechanical damage to the battery. The battery was inverted and the cells checked for signs of free electrolyte. All cells had visible, free electrolyte. As a further method of checking for cracked cell cases, a pressurized leak check was performed on individual cells. This test was not a requirement. Leak testing was conducted in the following manner: 1) Apply a pressure (through vent plug area) of 4.5 to 5.2/lbs/in/cell for a duration of three (3) minutes. 2) At end of three (3) minute pressurized stand, look for pressure droppage. All cells in the battery passed the leak test.

3.5.1.3 Sand and Dust

Sand and Dust testing was successfully completed on Test Specimen 6 on 7 August 1980. Dust testing was originally scheduled for 26 June 1980, but had to be delayed pending repairs on test equipment.

3.5.1.4 Salt Fog

Test Specimen 6 successfully completed Salt Fog testing on 12 June 1980. The battery was suspended by a rope in the chamber to permit uniform salt fog exposure.

3.5.1.4 Salt Fog (continued)

Upon completion of testing, a visual examination of the battery did not indicate any physical or mechanical damage as a result of salt fog testing.

3.5.1.5 Fungus

Test specimen 6 succsssfully completed Fungus testing on 1 April 1981. Eagle-Picher did not have the facilities to conduct Fungus testing and testing was contracted to the Associated Laboratories of Dallas, Texas. Fungus testing on the MAR-5013 was delayed until the MAR-5011 battery was ready to undergo testing in order to save the expense of establishing two Fungus cultures on separate occasions.

The discharged MAR-5013 battery was exposed for twenty-eight (28) days at $86^{o}F \pm 3.6\ ^{o}F$ and $95 \pm 5\%$ relative humidity to a spore suspension of a mixture of:

Chaetomium Globosum
Aspergillus Niger
Aspergillus Flavus
Penicillium Citrinum

After the twenty-eight (28) day exposure, the battery was visually inspected without observing the presence of living fungus, deterioration, or corrosion.

3.5.1.5 Fungus (continued)

In July 1981, open circuit voltages were taken and found to range from 0.85 - 0.30 volts. The battery had been in the discharged condition since February 1981 (5 months) and had an activated age of 14 months. The battery then was subjected to a low rate charge initially at 0.5 amps and later increased to 1.0 Amps and 1.5 Amps when it was evident the battery was accepting charge. Once charged, the battery was subjected to a 15.0 Amp discharge to a 24.3 volt cut-off. The battery delivered 18 ampere hours. The obtained 18 AH capacity was somewhat greater than expected for a battery containing electrochemical nickel electrodes that had been in the discharged condition for five (5) months, and had calendar life of fourteen (14) months.

In February 1981, the battery had delivered 17.6 ampere hours. Discharge at that time was concluded when the first cell in the battery reached 1.35 volts.

The additional cycle following fungus testing was not required, but was generated for characterization purposes concerning discharged storage.

3.5.2 Operating Tests

Battery testing for the operating portion of qualification test was not conducted with the MAR-5013 installed in the BQM-34A battery box since the purpose of the dynamic testing was to test the battery structure instead of the battery box structure. In tests requiring battery restraint (mechanical shock, vibration, and acceleration) the battery was rested on 1/8" thick cork. The battery was restrained by placing on 1/8 " thick neoprene rubber sheet (holes to allow for vent plug area) on top of the battery and on top of the rubber, a 1/2" aluminum plate also with drilled holes for cell vent areas. The aluminum plate also had drilled holes to enable six (6) threaded rods to be used to secure the battery to the test equipment.

3.5.2.1 Mechanical Shock

Test Specimen 1 successfully completed mechanical shock testing on 21 March 1980. The battery was charged on 20 March 1980 prior to testing. The required shock pulse the battery was supposed to be subjected to was a half sine wave with a 15 g peak and a duration of .011 seconds, however, it was not possible to obtain this with the shock apparatus. The actual shock applied was closer to a 21 g peak and a duration of .011 seconds.

Due to method of required battery restraint, individual cell voltages were not monitored during shock application. At this time, battery voltage was monitored using a recording oscillograph. At the

3.5.2.1 <u>Mechanical Shock</u> (continued)

conclusion of the shock applications, the fixture restraints were removed and individual cell voltages were monitored.

The three shock applications did not affect battery discharge in any manner. Discharge was conducted at 14 amps constant current until the first cell (cell #3) reached 1.35 volts. Figure 20 is a graph of the discharge. A total of 21.7 Amp-Hours was removed from the battery. This was the first discharge the battery was subjected to after the formation charge in January 1980.

3.5.2.2 <u>Vibration</u>

Vibration testing required the battery to be tested in the upright position with vibration applied in each of three mutually perpendicular axis for 30 minutes/axis (Z,Y, and X as shown in Figure 18). Discharge was interrupted between axis in order to reposition the battery on the vibrator. Discharge was conducted at 10 Amps.

Test Specimen 2 was subjected to vibration testing on 11 April 1980. Four and one half (4½) minutes into discharge, a stripped thread in the vibration slip table caused the test fixture to come loose and crack the end cell cases. See Figure 21.

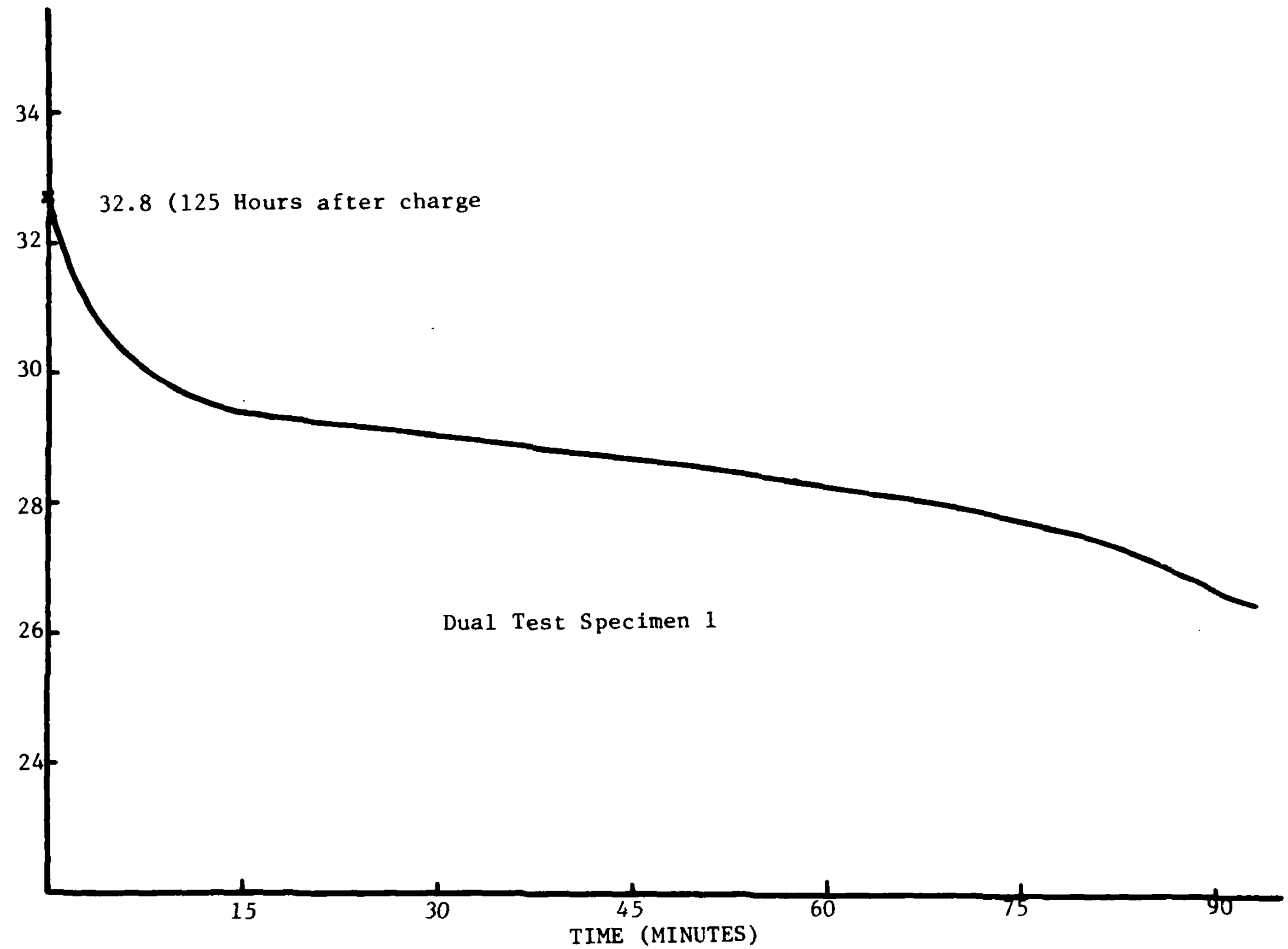

FIGURE 20

MECHANICAL SHOCK TESTING
14 AMP DISCHARGE

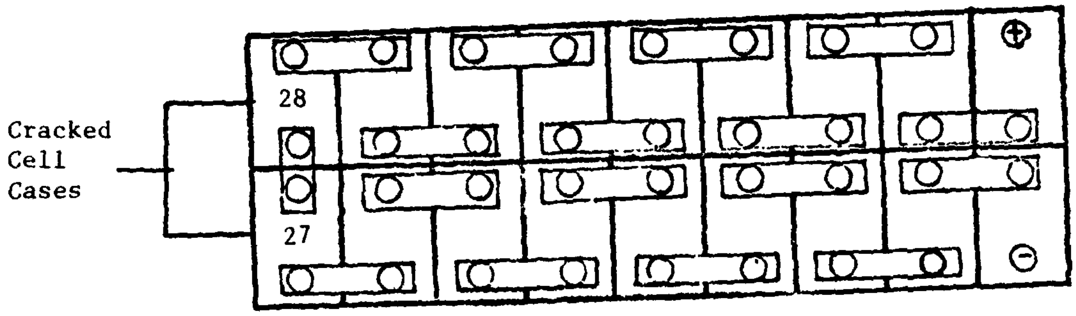

FIGURE 21

VIBRATION

TEST SPECIMEN 2

Testing was stopped and the battery was subjected to cell leak testing. Cells No. 27 and cell No. 28 failed the leak test.

3.5.2.2 Vibration (continued)

Originally, vibration testing was only scheduled for Test Specimen 2, however, after Test Specimen 2 experienced test fixture failure, vibration testing was conducted on Test Specimen 1. Test specimen 1 had already successfully completed its' scheduled tests.

Test specimen 1 was subjected to vibration testing on 29 April 1980. The battery completed all axis of vibration, and battery discharge performance was not affected. However, closer visual inspection of the battery revealed a small crack in the underneath side of the cross intercell connector. Refer to Figure 22.

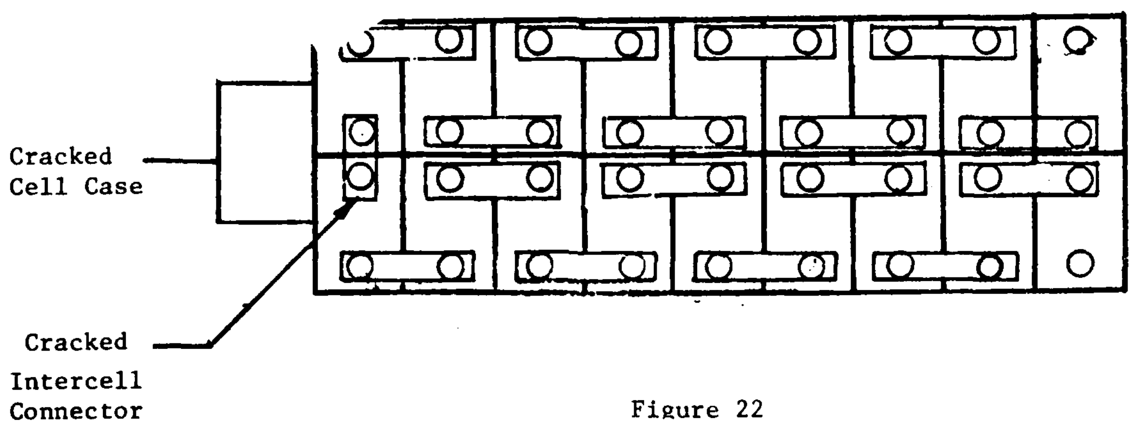

Figure 22

VIBRATION
TEST SPECIMEN 1

AD-A115 843 EAGLE-PICHER INDUSTRIES INC JOPLIN MO F/G 10/3
NICKEL-ZINC BATTERIES FOR RPV APPLICATIONS.(U)
FEB 82 D DAPPERT F33615-78-C-2058
UNCLASSIFIED AFWAL-TR-82-2003 NL

2 OF 2
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A115843

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3.5.2.2 Vibration (continued)

Cell leak checking revealed cells No. 9 and 10 to have cracked during testing. These were the same corresponding cells that cracked in Test Specimen 2. Most likely, the cells in the Test Specimen 2 would have cracked regardless of test fixture failure.

At this point, cells in the MAR-5013 battery were not potted solid in the MAR-5013 restraining tray. During vibration, particularly along the Y axis, the two rows of cells started moving independently of each other; tied together only by the cross intercell connector. This independent cell motion caused high stress areas along the cross intercell connector and resulted in cell case crackage.

In order to eliminate the stress areas, the cells would have to be potted in the container, therefore Test Specimen 3 was potted solid and the battery successfully completed vibration testing on 9 May 1980. Cell leak testing did not reveal any cracked cell cases.

A final vibration test was conducted on Test Specimen 6 (potted) on 20 June 1980, as a final verification potted MAR-5013's could meet vibration requirements. Test Specimen 6 successfully completed vibration. Cell leak testing did notreveal any cracked cell cases. Figure 23 and Figure 24 are graphs of

3.5.2.2 Vibration (continued)

vibration discharges for Test Specimen 3 and Test Specimen 6 .

3.5.2.3 Attitude

Attitude testing was successfully conducted on Test Specimen 1 (28 March 1980) and Test Specimen 2 (9 April 1980). Discharge was conducted at a 14 amp rate. Testing required the batteries be discharged at an angle of 60° from the Y axis and maintained for not less than ten minutes and not more than one-half of the anticipated discharge time. Discharge time 60° from the Y axis had the same time requirements as the X axis. Both batteries were discharged for twenty-six (26) minutes during 60° from the Y axis and X axis. The remaining portion of discharge was conducted with the battery in the normal upright postion. Discharge was concluded when the first cell in a battery reached 1.35 volts. Test Specimen 1 delivered 21.7 Amp Hours, and Test Specimen 2 delivered 19.4 Amp Hours . Figure 25 and Figure 26 represent the attitude discharges for Test Specimen 1 and Test Specimen 2 respectively.

3.5.2.4 Altitude

Test Specimen 1 was successfully was subjected to Altitude testing on 1 April 1980. Battery discharge

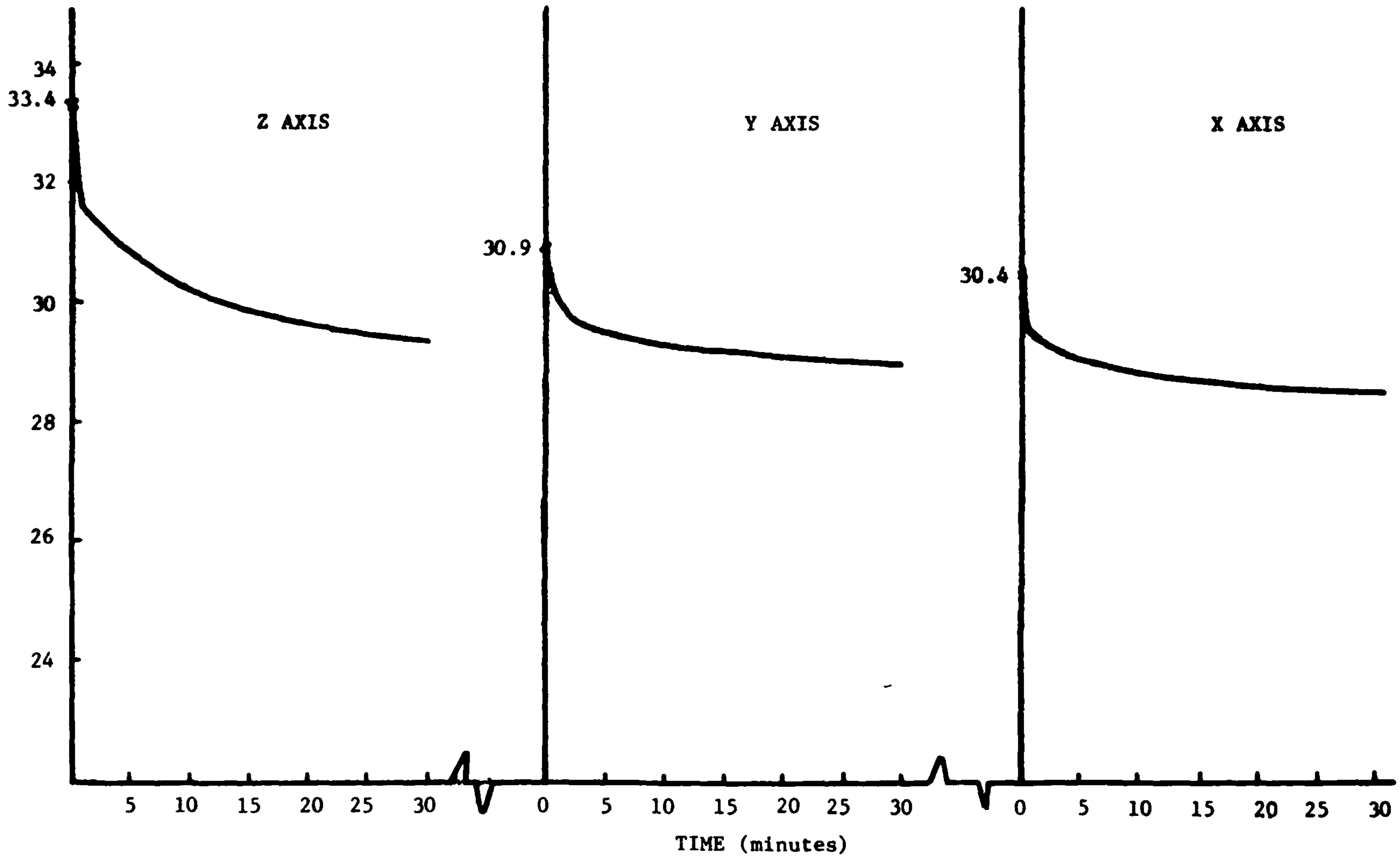


FIGURE 23

MAR-5013 VIBRATION
TEST SPECIMEN 3

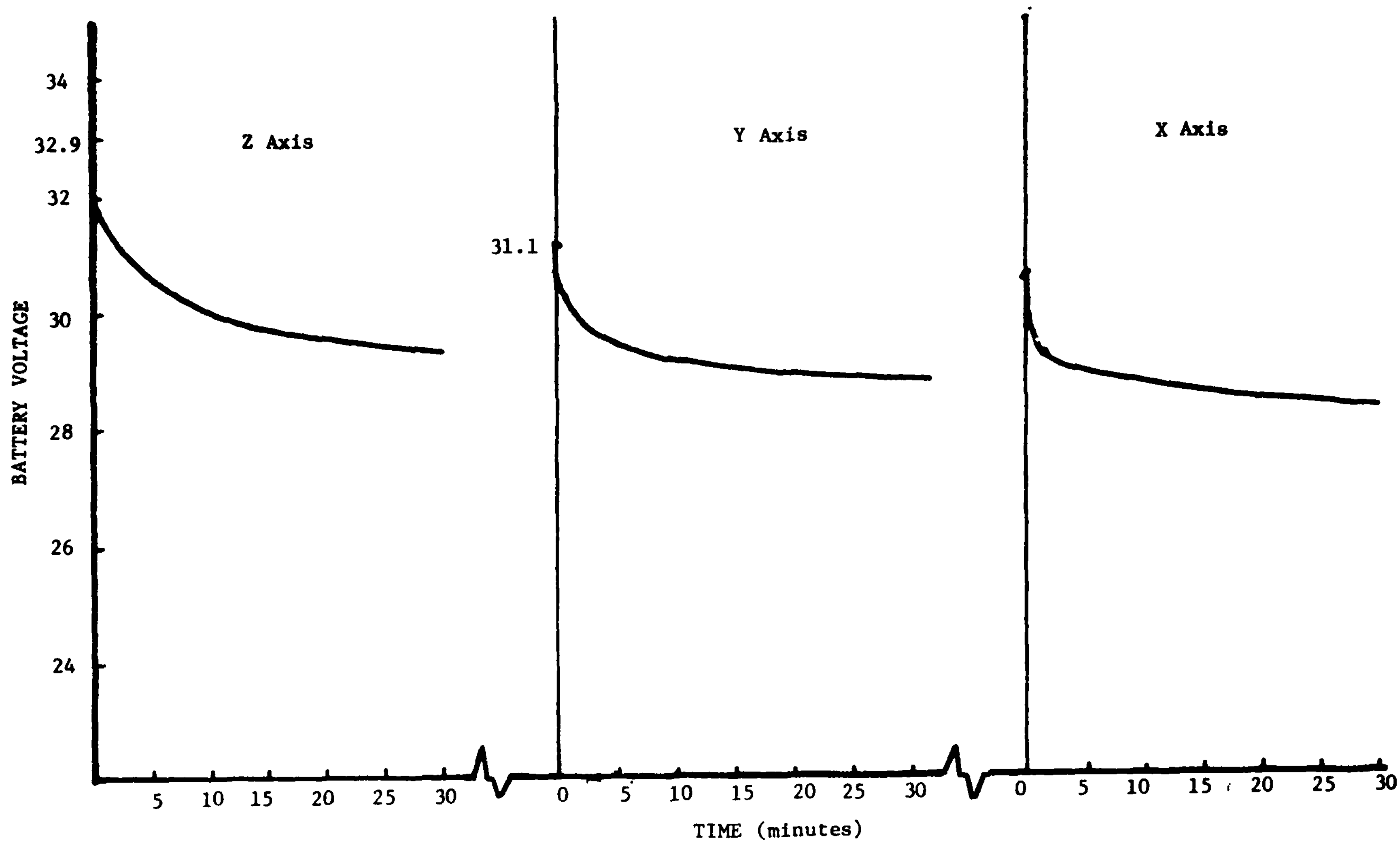


FIGURE 24

MAR-5013 VIBRATION
TEST SPECIMEN 6

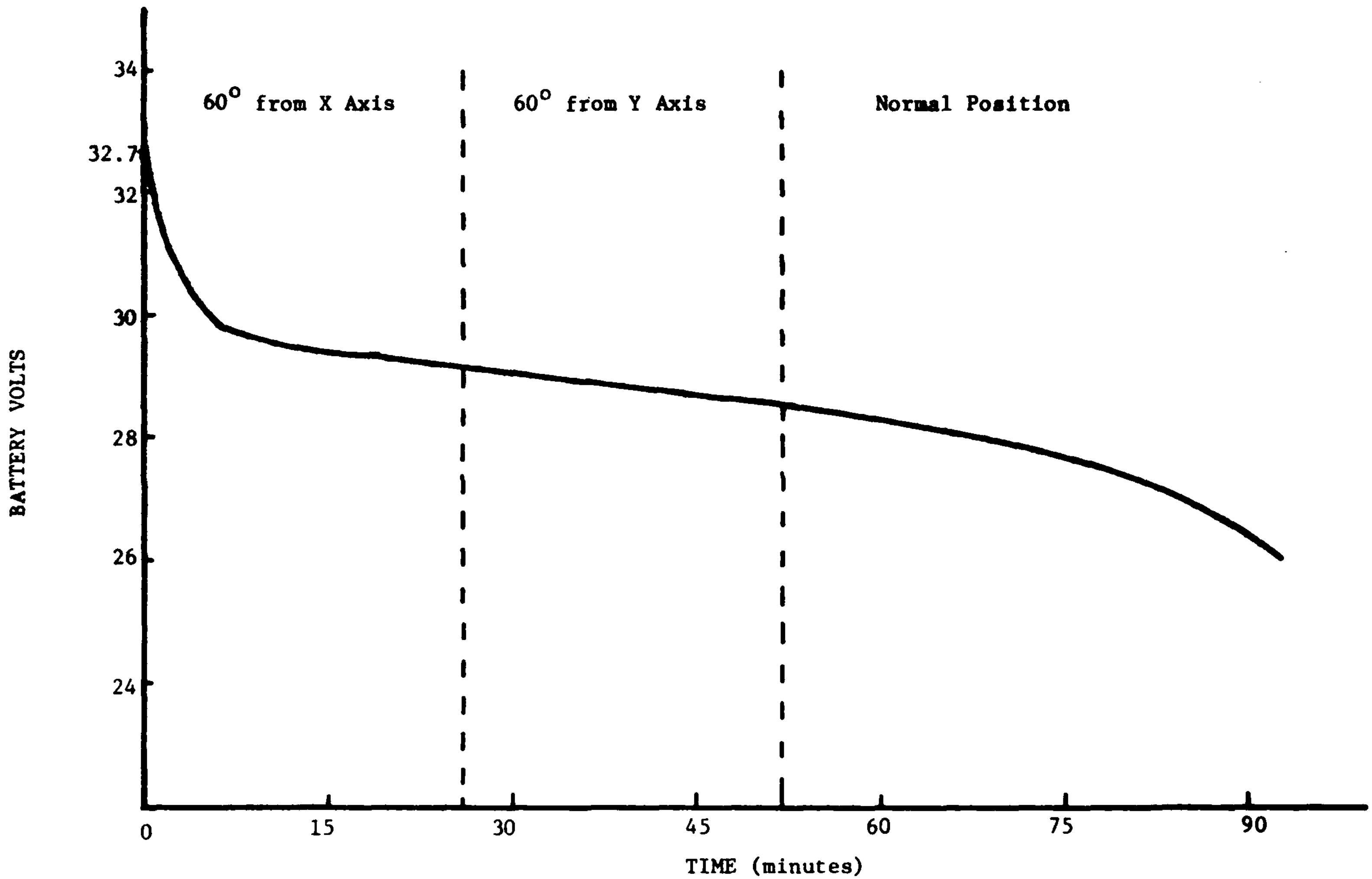


FIGURE 25

ATTITUDE
MAR-5013 TEST SPECIMEN 1
14 AMP DISCHARGE

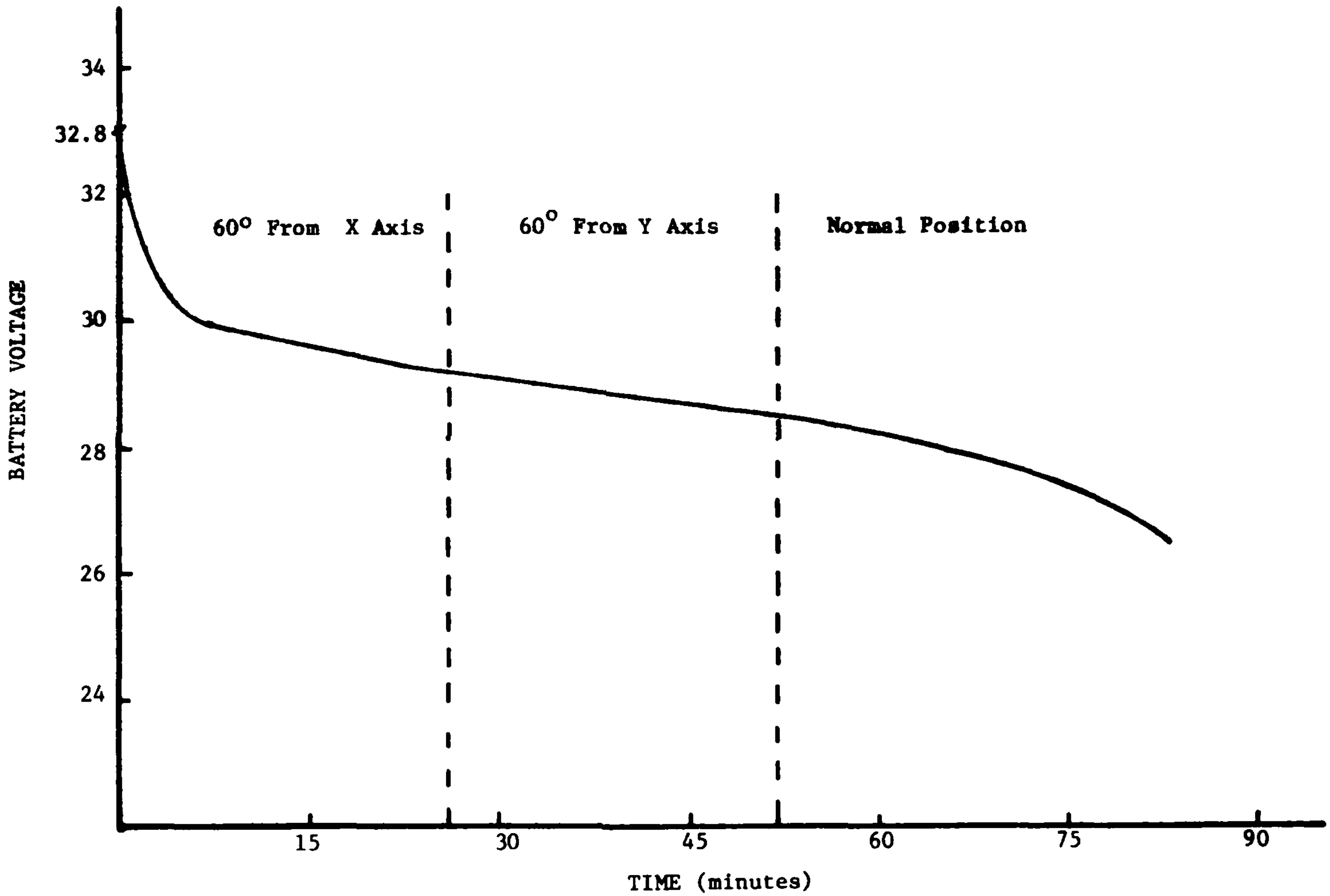


FIGURE 26

ATTITIDE
MAR-5013 TEST SPECIMEN 2
14 AMP DISCHARGE

3..5.2.4 Altitude (continued)

performance was not affected at a simulated altitude of 60,000 ft. for 15 minutes. Total duration discharge shall be one (1) hour at a 14 Amp rate.

It required seven (7) minutes to obtain the 28.9 in^2 chamber pressure necessary to simulated 60,000 ft. The battery was maintained at this pressure for fifteen (15) minutes. After fifteen (15) minutes, the battery was returned to room ambient conditions within a four (4) minute time interval. Discharge was continued at room ambient conditions for an additional thirty four (34) minutes for a total accumulated discharge time of one (1) hour. Figure 27 is a graph of the discharge.

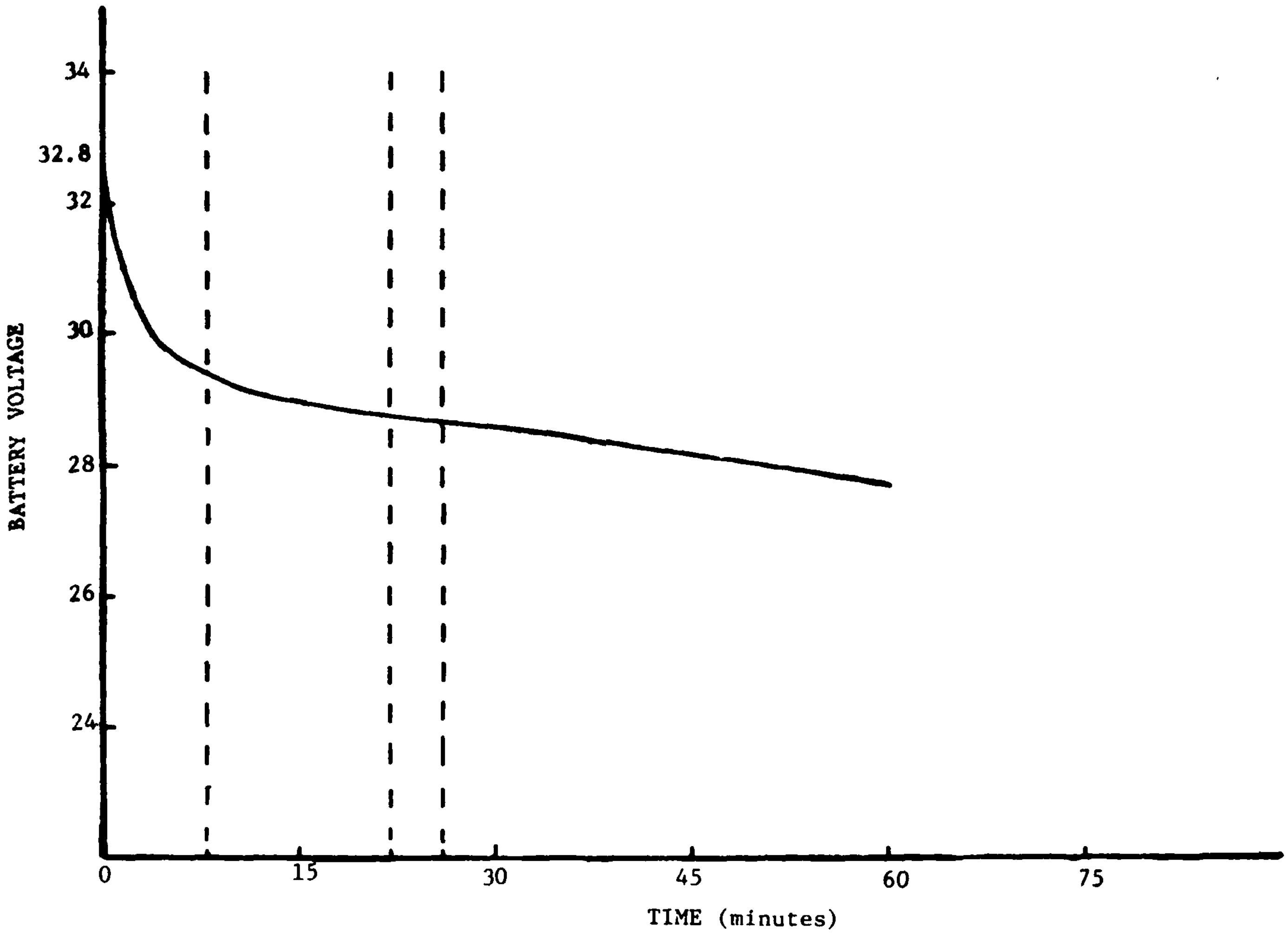


FIGURE 27

ALTITIDE
MAR-5013 TEST SPECIMEN 1
14 AMP DISCHARGE

3.5.2.5 Acceleration

Test Specimen 1 successfully completed acceleration testing on 17 April 1980. Visual examination of the battery at the conclusion of acceleration testing did not reveal evidence of physical or mechanical damage. Examination of oscillograph tapes of battery discharge during acceleration did not indicate electrical performance was affected by acceleration. Following acceleration, discharge was continued at a 14 amp rated until one cell in the battery reached 1.35 volts. Battery performance was normal. A total of 22.2 amp-hours was removed from the battery (including acceleration discharges).

3.5.2.6 Cycle Life - 15 Amps

Test Specimen 4 was subjected to cycle testing from 23 July 1980 to 17 July 1981. The battery successfully completed 105 cycles at or greater than an 80% DOD (18 AH) while maintaining a final discharge terminal voltage at or greater than 24.3 volts. Testing required the battery to deliver 100 cycles at the above conditions. Test data for the battery is summarized in Table 26 . Discharges 16, 24, and 35 are shown in Figure 28.

3.5.2.6 Cycle Life - 15 Amps (continued)

Discharges 53, 76, 95, and 112 are shown in Figure 29. Battery testing was conducted on automatic cycle equipment which cycled directly from charge to discharge.

TABLE 26

MAR-5013 QUALIFICATION CYCLE LIFE

15 AMP RATE

CYCLE NUMBER	DISCHARGE CAPACITY (AH)	FINAL BATTERY VOLTAGE
1 (Formation)	6.0 (45 Amps)	25.1
3	16.3	27.5
4	28.8	25.0 at 18 AH (16.0 Final)
5	26.7	26.4
6	18.5	28.5
11	26.0	25.6
14	18.0	28.5
21	18.0	28.1
25	18.0	28.1
30	18.0	27.7
35	18.0	27.7
40	18.0	27.3
45	18.0	27.3
50	18.0	27.3
53	18.0	27.4
57	18.0	26.7
61	18.0	27.0
65	18.0	26.7
72	18.0	27.1
75	18.0	27.0
79	18.0	26.8
83	18.0	26.6
87	18.0	28.8
90	18.0	26.6
95	18.0	26.4
99	18.0	25.8
108	18.0	24.3
109	18.0	* 24.3-16.5 AH 23.5 Final
111	18.0	* 21.6
112	18.0	24.3
113	16.6	* 20.3
115	17.25	* 24.3-16.75 AH - 23.5 Final
117	15.0	* 23.0

* Battery voltage below 24.3 volts.

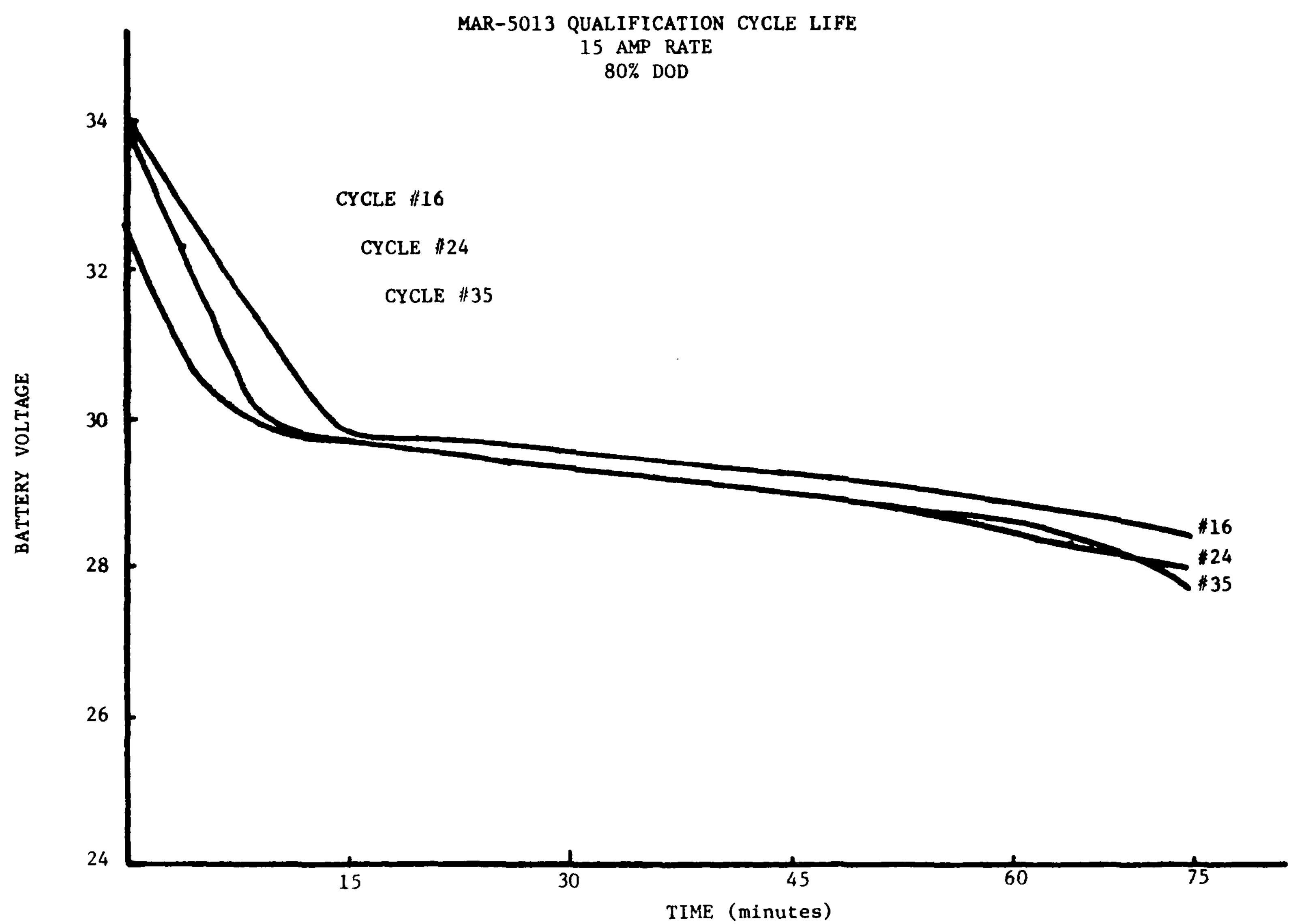


FIGURE 28
MAR-5013 QUALIFICATION CYCLE LIFE
15 AMP RATE - 80% DOD

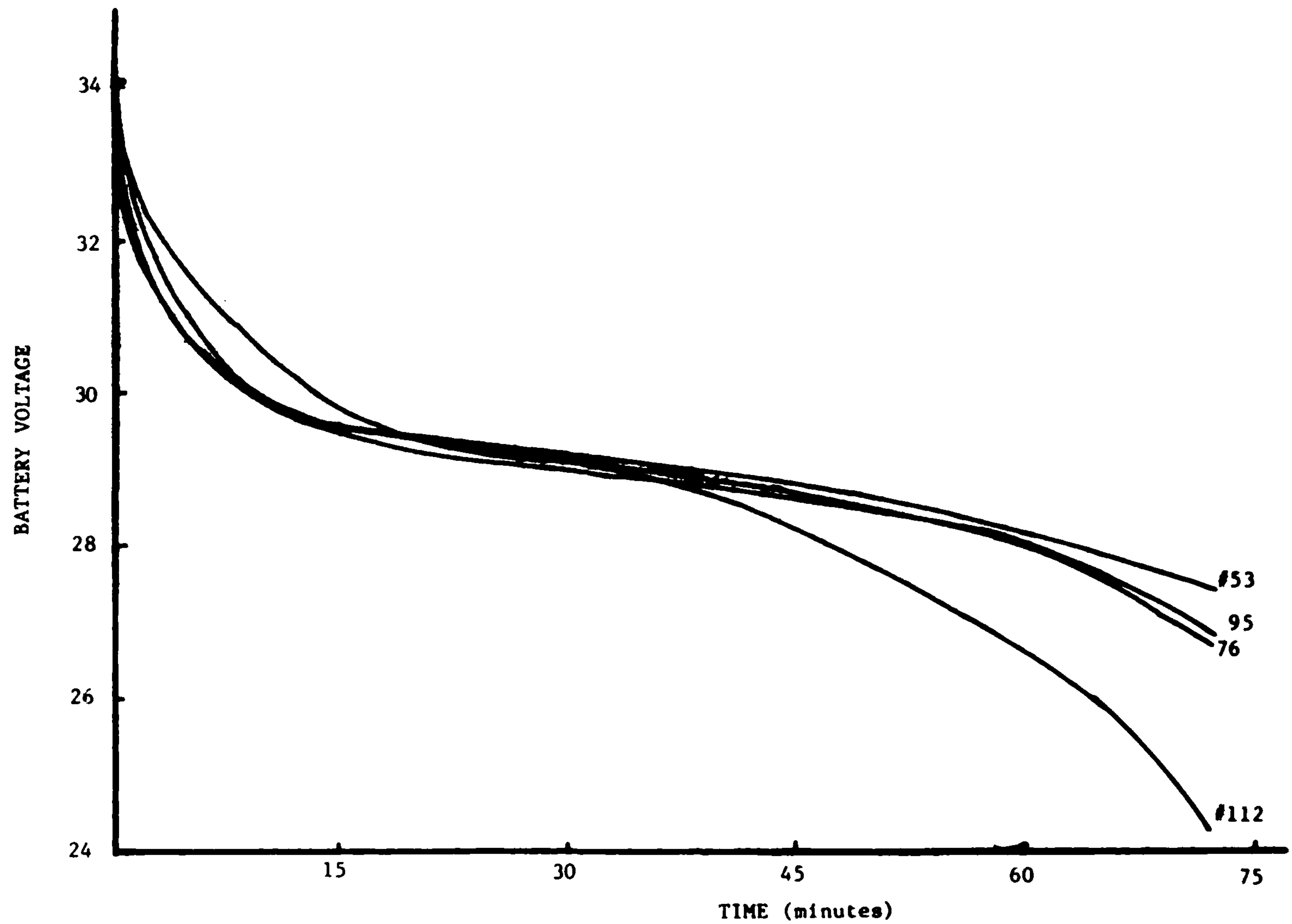


FIGURE 29
MAR-5013 QUALIFICATION CYCLE LIFE
15 Amp Rate - 80% DOD

3.5.2.7 Cycle Life - 45 Amps

Test Specimen 5 was subjected to cycle testing from 21 July 1980 to 5 February 1981. The battery successfully completed 50 cycles at or greater than a 50% DOD (11.25AH) while maintaining of final discharge terminal voltage at or greater than 24.3 volts. Testing required the battery to deliver 50 cycles at a 50% DOD of rated capacity. In actuality, the battery was subjected to greater than 50% DOD at the 45 Amp rate for cycles 3-10 and 12-14. Test data for the battery is summarized in Table 27. Discharges 5, 15, and 30 are shown in Figure 30. Discharges 45 and 55 are shown in Figure 31 .

TABLE 27

MAR-5013 QUALIFICATION CYCLE LIFE
45 AMP RATE

CYCLE NUMBER	DISCHARGE CAPACITY	FINAL BATTERY VOLTAGE
1	27.5 (15 Amps)	27.4
2	30.0 (15 Amps)	*24.1
3	18.0	25.6
4	18.0	26.0
5	18.0	26.2
6	18.0	25.8
7	18.0	25.5
8	14.3	26.3
9	15.0	26.3
11	28.5 (3 Amps)	25.6
*15	11.3	26.5
17	11.3	27.1
18	11.3	25.9
23	11.3	26.3
27	11.3	26.2
30	11.3	25.3
36	11.3	25.5
39	11.3	25.1
40	11.3	24.5
45	11.3	24.7
48	11.3	24.5
49	11.3	24.4
51	11.3	24.4
52	11.3	**22.8
53	11.3	**22.9
54	11.3	24.5
55	11.3	24.5

*Started 50% DOD Testing regime
** Below 24.3 volt cut-off

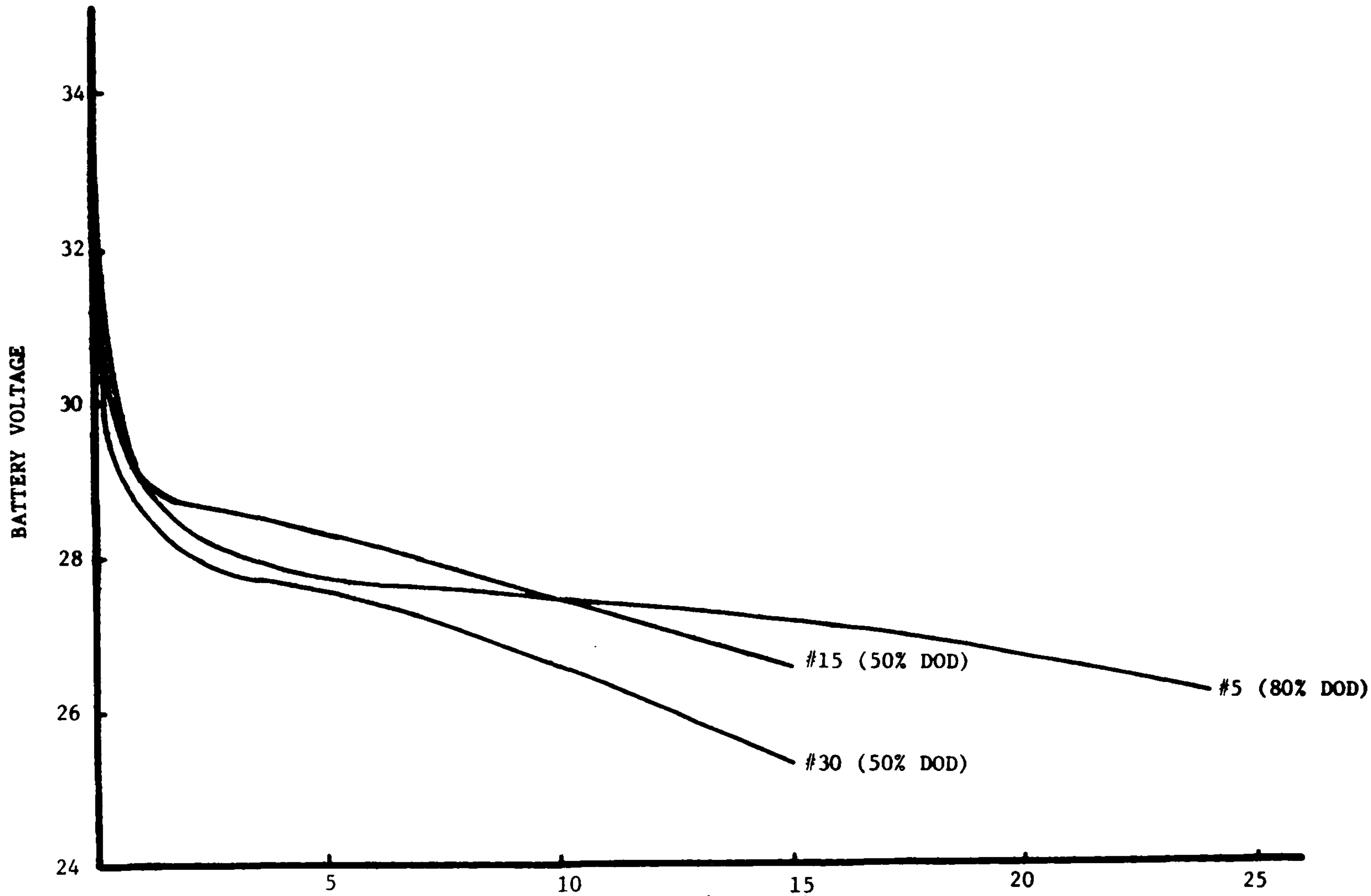


FIGURE 30
MAR-5013 QUALIFICATION CYCLE LIFE
45 AMP RATE

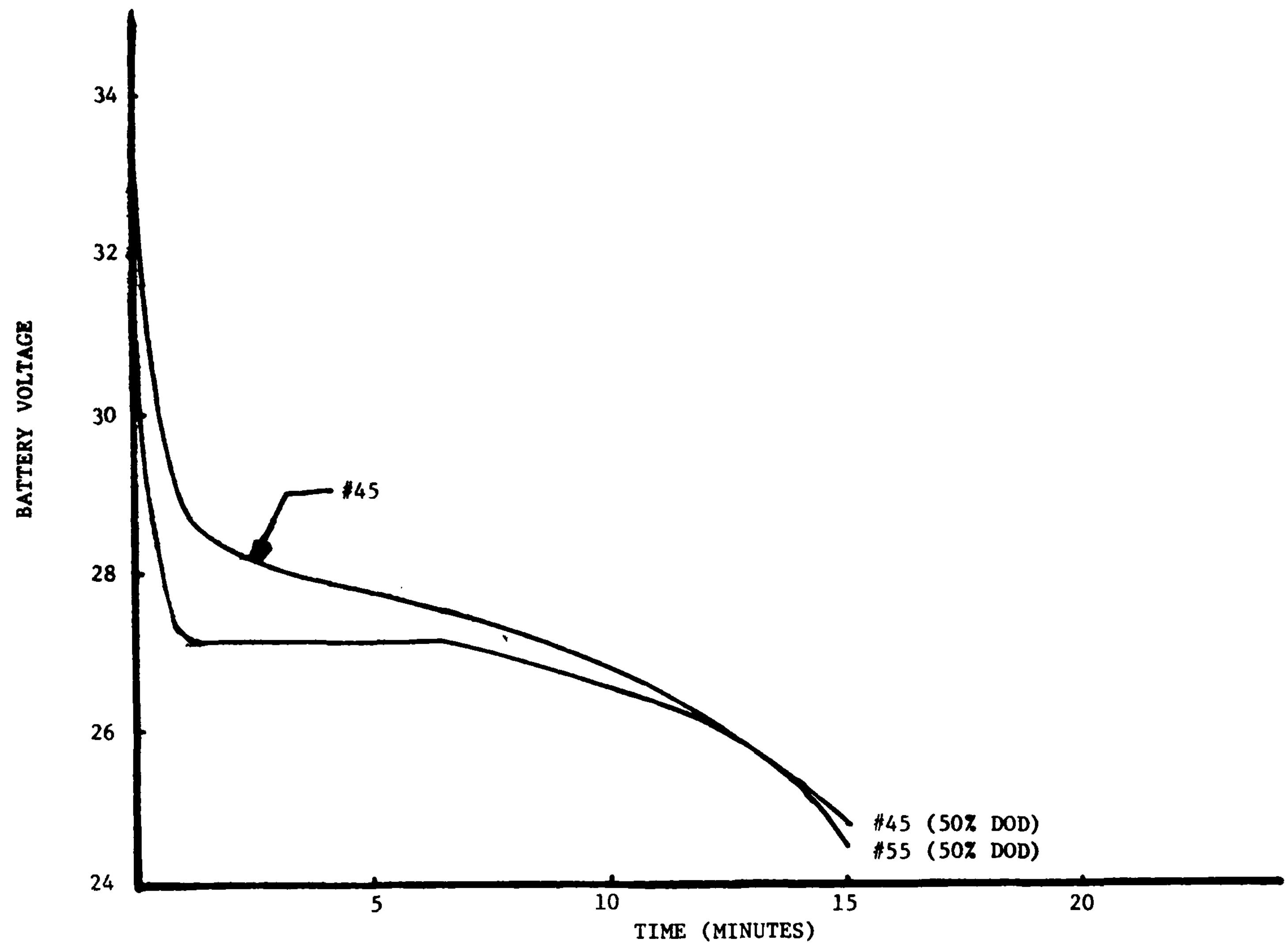


FIGURE 31
MAR-5013 QUALIFICATION CYCLE LIFE
45 AMP RATE

3.6 MAR-5013 Flight Batteries

A total of fifteen (15) Flight Test batteries were constructed and shipped to Tyndall AFB, Florida for testing in the BQM-34A remotely piloted target. Battery shipment was divided into two shipments.

3.6.1 MAR-5013 Flight Batteries - First Shipment

Seven (7) batteries were constructed and shipped to Tyndall AFB during July 1980. (The batteries were constructed with conventional vaccum impregnated nickel electrodes (Refer to Table 18 for cell characteristics) Five (5) of the seven (7) batteries were shipped activated, and the remaining two (2) batteries were shipped in the unactivated condition.

3.6.1.1 Activation

Activation of the MAR-5013 battery was accomplished manually. At the end of activation, the electrolyte level was between the top of the plates and the top of the separation. Cell electrolyte quantities for each battery are listed in Table 28.

The cell electrolyte quantity was decreased because of foaming problems encountered during the formation cycle on batteries with 80 cc of electrolyte per cell. Foaming resulted from the surfactant wetting agent in the Celgard 3400. With decreased electrolyte levels, foaming problems were not encountered. The electrolyte level in cells activated with 70 cc of electrolyte was still between the top of the plates and the top of the separation.

3.6 MAR-5013 Flight Batteries (continued)

3.6.1 MAR-5013 Flight Batteries - First Shipment (continued)

3.6.1.2 Battery Formation

The five batteries, activated at Eagle-Picher, were formed at a 5 Amp constant current rate. Amp-hour input was 150% of theoretical capacity. The batteries were discharged at a 15 amp rate. Discharge Amp Hour capacities for the seven batteries are listed in Table 28. Additional cycles were placed on Batteries 4 & 5 before shipment to Tyndall in order to improve AH capacity.

3.6.1.3 Battery Status

Approximately six (6) weeks into flight testing, the flight batteries were returned to Eagle-Picher for conditioning. The seventh battery was lost on a flight mission when the target drone was shot down. Refer to Table 28 for a summary of battery history prior to return to Eagle-Picher. Battery performance difficulties encountered at Tyndall were mainly caused by a combination of inadequate electrolyte volume and charging methods which caused cells to become out-of-balance and reach high charge voltages. Originally, the batteries were activated with a reduced amount of electrolyte in order to help reduce the foaming problems encountered with the electrolyte interacting with the separator wetting agent. The electrolyte

3.6 MAR-5013 Flight Batteries

3.6.1 MAR-5013 Flight Batteries - First Shipment

3.6.1.3 Battery Status (continued)

level was further reduced by charging methods at Tyndall. The batteries were charged, at least part of the time, without vent plugs which allowed for a reduction in electrolyte. Also, in some instances, the batteries were overcharged, which resulted in electrolyte (water) loss and further cell voltage imbalances.

3.6.1.4 Battery Inspection

The Flight Batteries were examined as received from Tyndall for evidence of damage. All six (6) batteries appeared extremely dry. There was no evidence of free electrolyte. Battery 2 went in the gulf when the drone was shot down. Examination of the battery indicated approximately two inches of salt water had stood in the drone battery box. The top of the battery showed signs of corrosions near the center cells around the terminal area. Examination of battery 7 indicated that this battery may have received an extremely deep discharge which generated internal cell heat and resulted in cell swelling. The battery was not reconditioned.

3.6.1.5 Battery Conditioning

The reconditioning procedure five (5) flight batteries were subjected to is described as follows:

3.6 MAR-5013 Flight Batteries

3.6.1 MAR-5013 Flight Batteries - First Shipment

3.6.1.5 Battery Conditioning (continued)

1. Record open circuit voltages.
2. Add electrolyte until the level is at the top of the separation.
3. Low rate 3 amp constant resistance discharge to a cut-off voltage of 0.3 volts per cell.
4. 3.0 Amp constant current charge.
5. Low rate 3.0 amp constant resistance discharge until the first cell reaches 1.35 volts.
6. Three additional cycles:

   A. Charge: 3.0 amps constant current.

   B. Discharge: 15.0 amp constant resistance discharge until the first cell reaches 1.35 volts.

3.6.1.6 Battery Conditioning Results

The capacity performance of the batteries while at Eagle-Picher is summarized in Table 29. All discharges are constant resistance discharges.

TABLE 28

MAR-5013 FLIGHT BATTERIES STATUS

SPECIMEN NO.	FORMATION CHARGE	FORMATION DISCHARGES 15 Amp Constant Current	RECHARGES	TOP CHARGE	LOAD CHECKS 20 Amp 5 Min	CAPACITY CHECK (15 Amp) Discharge 12.5 AH Minimum	FLIGHT MISSION
1	At E-P 80 cc Electrolyte per cell	#1 23.8 AH	2	5	2	2	1
2	At E-P 80 cc Electrolyte per cell	#1 30 AH	4	2	1	4 Failed to meet last check	4 Went in gulf with drone
3	At E-P 80 cc Electrolyte per cell	#1 29.5 AH	1	1	0	Acceptable before de- stroyed in flight	1 Lost battery drone shot down
4	At E-P 75 cc Electrolyte per cell	#1 23 AH #2 28.3 AH	4	4	1	5 Failed to meet last check	1
5	At E-P 70 cc Electrolyte per cell	#1 22.5 AH #2 24.1 AH #3 27.3 AH	5	2	1	6 Failed to meet last 2 checks	0 Bench Battery
6	Shipped Dry 70 cc Electrolyte per cell at Tyndall	#1 26.25 AH At Tyndall	1	4	Invalid	2	0
7	Shipped Dry 70 cc Electrolyte per cell at Tyndall	#1 Data not known	4	0	0	Met standard Until destroyed in shop	0

TABLE 29

FLIGHT BATTERY CAPACITY PERFORMANCE

BATTERY NO.	Open Circuit Voltage Range	DISCHARGE 3 Amp 0.3 v/cell Cut-off	3 Amp	15 Amp	15 Amp	15 Amp
1	1.74-1.75	27 AH	26	26	27	27
2	All 1.73	21	26	24	27	25
4	All 1.74	32	28	28	28	27
5	1.72-1.73	23	27	27	26	26
6	All 1.71	14	29	26	26	28

Battery performance at the end of the conditioning procedure exceeded the 12.5 AH service capacity requirement. At this point the batteries were shipped back to Tyndall AFB.

3.6.2 MAR-5013 Flight Batteries Second-Shipment

Eight (8) batteries were constructed and shipped to Tyndall AFB during March 1981. The batteries were shipped in the unactivated condition. The batteries were constructed with conventional vaccum impregnated nickel electrodes and incorporated copper grid and tab material in the negative electrodes (Refer to Table 19 for cell characteristics).

SECTION II

MAR-5011

1.0 INTRODUCTION

The objective of this portion of the program is to develop the technology necessary for a long-life, low cost, rechargeable nickel-zinc battery as a replacement for existing lead-acid batteries used in PQM-102 target drones. The nickel zinc batteries herein described (Eagle-Picher Part No. MAR-5011) potentially have a wider range of applications than the more specialized MAR-5013 battery. The MAR-5011 nickel-zinc batteries are to be physically and electrically interchangeable with the existing lead-acid batteries. The current lead acid battery is 18 Amp Hours constructed in a 22 Amp Hour nickel cadmium battery box.

The general technical requirements for the nickel-zinc battery are:

1) Battery voltage shall be compatible to the vehicle electrical system. (24 volt nominal)
2) Battery charging requirements compatible to existing ground charging equipment.
3) Battery weight for the filled, complete, flight ready battery shall not exceed 56 pounds.
4) Battery cycle life shall exceed 120 cycles.
5) Battery operation shall be able to be conducted in a temperature range of $0^{o}F$ to $165^{o}F$.

2.0 BATTERY DESIGN

The nickel-zinc battery to potentially be used for the PQM-102 target drone has been assigned Eagle-Picher battery Number MAR-5011. The general characteristics of this battery are listed in Table 30. Figure 32 is a picture of a MAR-5011 battery. Figure 33 shows the MAR-5011 battery with the cover removed.

TABLE 30
MAR-5011 BATTERY DESIGN

NUMBER OF CELLS:	15
BATTERY WEIGHT:	50 lbs.
SIZE:	7.66" x 9.96" x 8.75"
NOMINAL VOLTAGE:	24V
OPEN CIRCUIT VOLTAGE, CHARGED:	26.5 - 28V
OPEN CIRCUIT VOLTAGE, DISCHARGED:	24.5 - 26V
SPECIFICATION OPEN CIRCUIT VOLTAGE:	26 - 28V
CELL CASE MATERIAL:	SAN, Plastic, Transparent to check electrolyte level

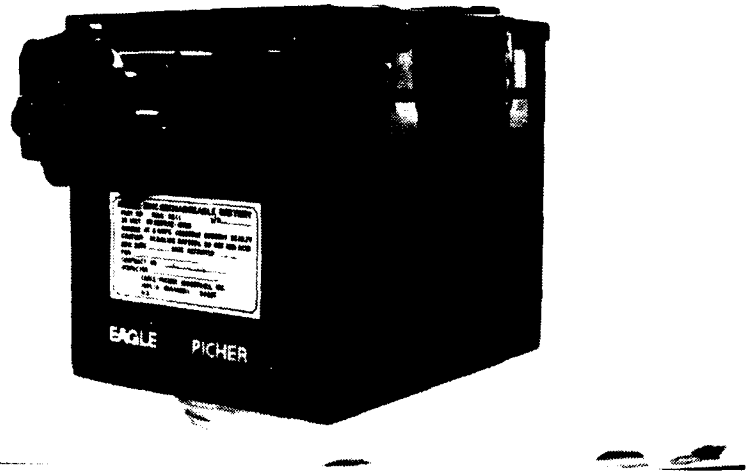


FIGURE 32

MAR-5011 BATTERY

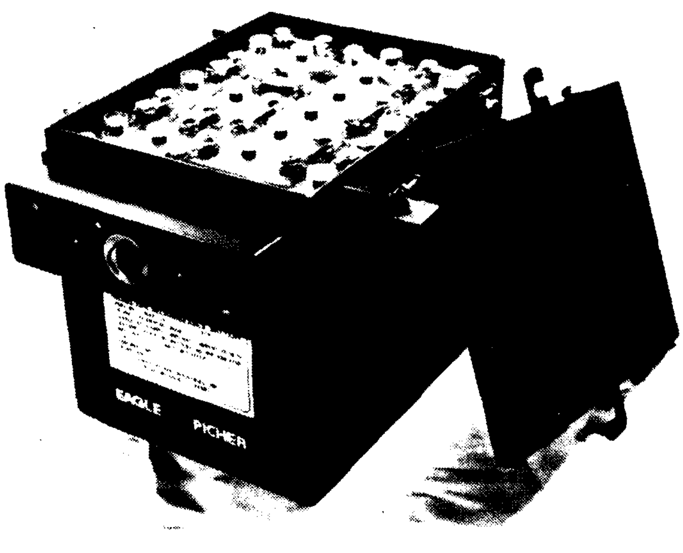


FIGURE 33

MAR-5011 BATTERY

(Cover Removed)

3.0 CELL DESIGN

The MAR-5011 individual cell characteristics are listed in Table 31 and Table 32 respectively. Table 31 lists cell characteristics for cells containing electrochemical nickel electrodes. Table 32 lists cell characteristics for cells containing conventionally impregnated nickel electrodes. A MAR-5011 cell is pictured in Figure 34 .

TABLE 31
MAR-5011 CELL DESIGN

CONFIGURATION:	14 Single Pos/15 Neg
ELECTRODE SIZE:	6.30" x 2.96"
POSITIVE ACTIVE MATERIAL LOADING:	.65 gm/in^2
TYPE POSITIVE ELECTRODE:	Electrochemical impregnation on .025" slurry sinter
POSITIVE THEORETICAL CAPACITY:	46.4 AH
POSITIVE TAB TO TERMINAL CONNECTION:	Bolted
NEGATIVE ACTIVE MATERIAL LOADING:	1.0 gm/in^2, no additives
NEGATIVE ELECTRODE THICKNESS:	.023"
NEGATIVE ELECTRODE DENSITY:	45 gm/in^3
RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY:	3.53/1
SEPARATOR:	Pellon, 3 Celgard/3 Cellophane, Pellon
CELL SURFACE AREA:	493 in^2
ELECTROLYTE:	31% KOH, No additives

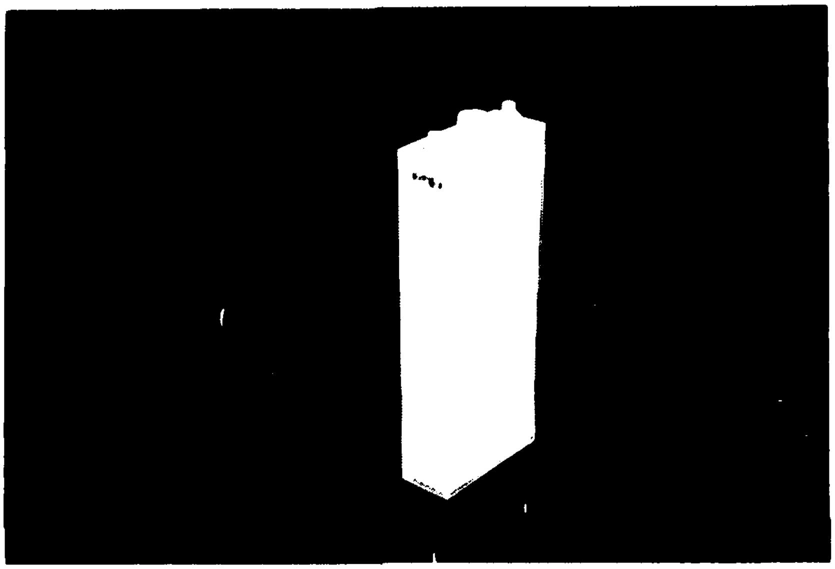


FIGURE 34
MAR-5011 CELL

TABLE 32

MAR-5011 CELL DESIGN (conventional)

CONFIGURATION:	13 Single Pos/14 Neg
ELECTRODE SIZE:	6.30" x 2.96"
POSITIVE ACTIVE MATERIAL LOADING:	.80 gm/in^2
TYPE POSITIVE ELECTRODE:	Conventional Impregnation Dry Sinter
POSITIVE THEORETICAL CAPACITY:	53.1 AH
POSITIVE TAB TO TERMINAL CONNECTION:	Bolted
NEGATIVE ACTIVE MATERIAL LOADING:	1.0 gm/in^2, No additives
NEGATIVE ELECTRODE THICKNESS:	.023"
NEGATIVE ELECTRODE DENSITY:	45 gm/in^3
RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY:	2.84/1
SEPARATOR:	Pellon, 3 Celgard/2 Cellophane, Pellon
CELL SURFACE AREA:	458 in^2
ELECTROLYTE:	31% KOH, No additives

The MAR-5011 battery has single positive plates. The single plate configuration was selected instead of double plates, as in the MAR-5013, because the MAR-5011 battery has a wider range of applications and could possibly require operation at lower temperatures than the MAR-5013.

4.0 MANUFACTURE OF MAR-5011

A total of twenty-four MAR-5011 batteries were manufactured. Batteries were constructed for Calendar and Cycle Life Testing, Qualification Testing, and PQM-102 Flight Testing. Table 33 is a breakdown of battery test types.

TABLE 33

MAR-5011 BATTERY MANUFACTURE

TYPE BATTERY	NUMBER MANUFACTURED
Calendar and Cycle Life Testing	3
Qualification Testing	6
Flight Testing	15

4.1 MAR-5011 Calendar & Cycle Life Batteries

Three (3) MAR-5011 batteries were constructed for Calendar & Cycle Life Testing. Batteries were constructed with Electrochemical nickel electrodes before capacity fading in the MAR-5013's became evident. Routine charging of the Calendar & Cycle Life Batteries consisted of an 8 Amp constant current charge until battery voltage reached 28.8 volts. Once this voltage was reached, charging was completed by an 8 amp limited constant potential charge until total AH input was 105 - 110 percent of the previous discharge. Routine discharging was initially conducted at 19.1 amps constant current, but later changed to 26 amps initial constant resitance. Battery discharge was concluded when the one cell in the battery reached 1.35 volts. At the end of this reporting period, the MAR-5011 Calendar and Cycle Life Batteries are sixteen (16) months old (activated age).

4.1.1 Calendar and Cycle Life - Battery 1

Battery 1 received a total of 56 cycles at the conclusion of testing. Discharge results are presented in Table 34. Activation methods were investigated with Battery 1 to determine if different activation methods affected cell performance. Cells 1-8 were manually activated and cells 9-15 were vaccum activated. All cells "soaked" 72 hours prior to formation charging. No performance differences were observed in the first or subsequent discharges.

As indicated in Table 34, capacity fading was evidenced in the discharge results. Cycles 6-10 were intentional shallow discharges to determine if subsequent discharge performance would be affected for deeper discharges. Discharge results obtained in Cycle 11 did not indicate performance was affected; the nickel-zinc system does not have the "memory" characteristics a nickel-cadium system does.

A condition discharge was placed on the battery during cycle 19 in an attempt to improve battery capacity. All cells in the battery were discharged to 0.3 volts and recharged. Battery performance was not improved in subsequent cycles.

At the conclusion of testing, cycle 56, the battery delivered 24.1 AH to battery cut-off voltage. The existing PQM-102 service capacity is 18 AH.

4.1.2 Calendar and Cycle Life - Battery 2

Battery 1 received a total of 132 cycles at the conclusion of testing. Discharge results are presented in Table 35. Battery performance did not differ significantly from Calendar and Cycle Battery 1. In order to accumulate cycles at a faster rate, the battery was placed on an automatic cycle system. Discharge was conducted

4.1.2 Calendar and Cycle Life - Battery 2 (continued)

at 8.0 amps for 2 Hr 40 Min.

During charge 96, maintenance personnel dropped a tool on the battery while working on laboratory equipment. Fourteen (14) cells were affected by the short, and two terminals were damaged. Cells in the battery became imbalanced which affected charge characteristics and discharge performance. As a method to balance the cells, the battery was subjected to an 8 Amp constant resistance discharge until cell voltage was 0.3 volts (discharge 100). Cell performance for cycle 101 and subsequent cycles was normal in comparison to cell performance prior to battery shortage.

At the conclusion of testing, cycle 132, the battery delivered 21.2 AH to a cut-off voltage of 20.5 volts.

4.1.3 Calendar and Cycle Life - Battery 3

Battery 3 received a total of 59 cycles at the conclusion of testing. Discharge results are presented in Table 36. Battery performance did not differ significantly from that of Calendar and Cycle Life Battery 1 or Calendar and Cycle Life Battery 2.

At the conclusion of testing, Cycle 59, the battery delivered 21.1 AH to a cut-off volgage of 20.2 volts.

TABLE 34
MAR-5013 CALENDAR AND CYCLE LIFE

Battery 1

Cycle Number	Days Between Charge/Discharge	Discharge Rate (Amps)	Discharge Capacity (AH)
1 (Formation)	1	19.1 A cc*	29.8 (21.4V)
2	1	19.1 A cc	34.0 (21.4V)
3	1	19.1 A cc	34.9 (20.2V)
4	0	19.1 A cc	34.3 (22.9V)
5	0	19.0 A cc	34.5 (22.9V)
6	0	19.0 A cc	*** 17.1 (24.9V)
7	0	19.0 A cc	*** 17.1 (24.5V)
8	0	19.0 A cc	*** 16.8 (24.5V)
9	0	19.0 A cc	*** 17.1 (23.9V)
10	0	19.0 A cc	*** 17.1 (24.1V)
11	0	19.0 A cc	35.6
12	0	19.0 A cc	32.5 (23.2V)
13	0	22.3 A @ 1 Hr Cr*	32.6 (22.1V)
14	0	23.0 A @ 1 Hr Cr	33.6
15	0	24.2 A @ 1 Hr Cr	34.8
16	0	24.0 A @ 50 Min Cr	32.9
17	2	23.4 A @ 1 Hr Cr	30.2 (22.4V)
18	1	23.8 A @	29.7
19	3	23.7 A @ 1 Hr Cr	50.6 (conditioning)
20	0	22.8 A @ 80 Min Cr	31.4
21	0	22.6 A @ 65 Min Cr	29.3
22	0	22.8 A @ 64 Min Cr	31.4
25	1	22.5 A @ 1 Hr Cr	28.5
30	0	22.5 A @ 67 Min Cr	28.6
33	0 1 Hr Disch	20.6 A @ 1 Hr Cr	23.6
34	0 1 Hr Disch	22.5 A @ 1 Hr Cr	23.9
35	0 45 Min Disch	24.6 A @ 45 Min Cr	19.0
40	0 45 Min Disch	24.2 @ 45 Min Cr	19.4
43	0 45 Min Disch	24.0 @ 45 Min Cr	18.8
44	0	22.3 @ 69 Min Cr	28.7
Battery sat Discharged 6 Weeks			
45	0 45 Min Disch	24.8 A @ 45 Min Cr	19.3 (23.8V)
46	0 1 Hr Disch	23.7 A @ 1 Hr Cr	25.6 (22.9V)
48	0 45 Min Disch	21.8 A @ 45 Min Cr	17.4 Cell Reversal
52	0	25 A cc	17.1 Cell Reversal
55	0	22.9 A @ 50 Min Cr	20.5 (20.2V)
56	0	14.2 A cc	24.1 (20.2V)

* cc = constant current
** Cr = Constant resistance
*** Intentional 54 Min. discharge

TABLE 35

MAR-5011 CALENDAR AND CYCLE LIFE

Battery 2

Cycle Number	Days Between Charge/Discharge	Discharge Rate (Amps)	Discharge Capacity (AH)
1 (Formation)	0	*19.1 A cc	32.3
2	0	19.1 A cc	33.7 (20.2V)
3	0	19.1 A cc	33.3 (20.5V)
Battery Stored Discharged for 4 Weeks			
4	0	19.0 A cc	30.7
5	0	19.1 A cc	34.0 (21.1V)
6	0	**22.3 A @ 50 Min Cr	34.1
8 34°F	0	80 A cc	8.0 (20.3V)
10	0	23.0 A @ 70 Min Cr	29.7
11	0	23.0 A @ 75 Min Cr	26.2
12	0	23.0 A @ 60 Min Cr	32.3
13	0	23.2 A @ 50 Min Cr	30.3
14	0	Discharge Interrupted	11
15	6	22.6 A @ 52 Min Cr	28.6
16	0	22.8 A @ 1 Hr Cr	30.5
17	1	22.6 A @ 55 Min Cr	27.2
19	1	22.0 A @ 75 Min Cr	30.1
20	1	22.6 A @ 65 Min Cr	31.3
21	1	23.0 A @ 50 Min Cr	30.7
22	0	1 Hr Disch 22.4 A @ 1 Hr Cr	23.5
23	1	1 Hr Disch 22.4 A @ 1 Hr Cr	23.5
25	0	1 Hr Disch 22.2 A @ 1 Hr Cr	23.5
30	1	1 Hr Disch 21.7 A @ 1 Hr Cr	23.2
35	0	1 Hr Disch 22.1 A @ 1 Hr Cr	24.0
45	0	22.9 A @ 48 Min Cr	20.1
46	0	21.6 A @ 1 Hr Cr	20.0 (21.6V)
Battery on Automatic Cyclers - 8.0 A cc for 2 Hr 40 Min.			
47	0	8.0 A cc	21.3 (24.2V)
55	0	8.0 A cc	21.3 (23.6V)
68	0	8.0 A cc	21.3 (22.9V)
75	0	8.0 A cc	21.3 (22.5V)
85	0	8.0 A cc	21.3 (23.8V)
95	0	8.0 A cc	21.3 (23.1V)
***96	0	8.0 A cc	20 (21.4V)
99	0	8.0 A cc	14.7
100	0	8.A Cr	conditioning
101	0	8.0 A cc	21.3 (23.1V)
109	0	8.0 A cc	21.3 (23.3V)
124	0	8.0 A cc	21.3 (22.9V)
130	0	8.0 A cc	21.3 (23.1)
132	0	10.5 A cc	21.2 (20.5V)

* cc = constant current

** cr = constant resistance

*** battery externally shorted with tool during charge

TABLE 36
MAR-5011 CALENDAR AND CYCLE LIFE

Battery 3

Cycle Number	Days Between Charge/Discharge	Discharge Rate (Amps)	Discharge Capacity (AH)
1 (Formation)	0	* 19.1 A cc	32.7 (23.0V)
2	1	19.1 A cc	33.7
3	0	19.1 A cc	33.3 (23.0V)
4	1	19.1 A cc	32.3
5	0	19.1 A cc	34.0
6	0	19.0 A cc	33.3
7	0	19.0 A cc	Unknown
8	0	19.0 A cc	31.7 (23.1V)
9	1	19.0 A cc	32.4
10	1	19.0 A cc	31.7
11	1	19.0 A cc	30.8
12	2	19.0 A cc	30.8 (22.5V)
13	1	19.0 A cc	31.7 (20.5V)
14	1	19.0 A cc	31.4
15	1	19.0 A cc	31.8
16	3	19.0 A cc	29.2 (20.6V)
17	0	19.0 A cc	31.4 (23.1V)
18	0	19.0 A cc	31.8 (22.7V)
19	0	** 22.7 A @ 1 Hr Cr	33.4 (22.3V)
20	0	23.7 A @ 1 Hr Cr	33.2
21	0	23.8 A @ 1 Hr Cr	32.3
25	1	22.0 A @ 73 Min Cr	30.8
30	1	22.2 A @ 42 Min Cr	18.4
35	0	22.8 A @ 38 Min Cr	15.0 (23.9V)
36	0	20.3 A @ 53 Min Cr	21.7 A
37	0 45 Min Disch	23.7 A @ 45 Min Cr	19.1 A
40	0 45 Min Disch	24.1 A @ 45 Min Cr	19.1 A
45	0 45 Min Disch	23.9 A @ 45 Min Cr	19.0 A
48	0	22.8 A @ 62 Min Cr	25.8 (21.6V)
49	0	25 A cc	22.4 (21.5V)
52	0	21.2 A @ 41 Min Cr	17.0 (21.2V)
54	0	21.1 A @ 46 Min Cr	19.2 (23.6V)
59	0	14.2 A cc	21.1 (20.2V) Cut-off

* cc = constant current
** cc = constant resistance

4.0 MANUFACTURE OF MAR-5011

4.2 Qualification Batteries

A total of six (6) MAR-5011 batteries were constructed for qualification testing purposes. Special battery characteristics are listed in Table 37. Testing was conducted per QTP-258 and MIL-STD-810. Battery orientation for testing is shown in Figure 35.

TABLE 37

MAR-5011 QUALIFICATION BATTERIES

TEST SPECIMEN NUMBER	POSITIVE CONFIGURATION	NEGATIVE GIRD MATERIAL
1	Electrochemical	Silver
2	Electrochemical	Copper
3	Conventional	Silver
4	Conventional	Silver
5	Conventional	Copper
6	Electrochemical	Copper

Copper grid material was incorporated in batteries because copper grid test cells constructed in the Third Series Developmental Test Cells cycled equally as well as silver grid test cells. Electrochemical nickel plates were used in those batteries subjected to dynamic test. Conventional plates were incorporated in those batteries where capacity performance was significant to testing. All future constructed MAR-5011 batteries will incorporate conventional positive electrodes.

The environmental Qualification test matrix the batteries were subjected to is outlined in Table 38.

TABLE 38

MAR-5011 QUALIFICATION TESTING

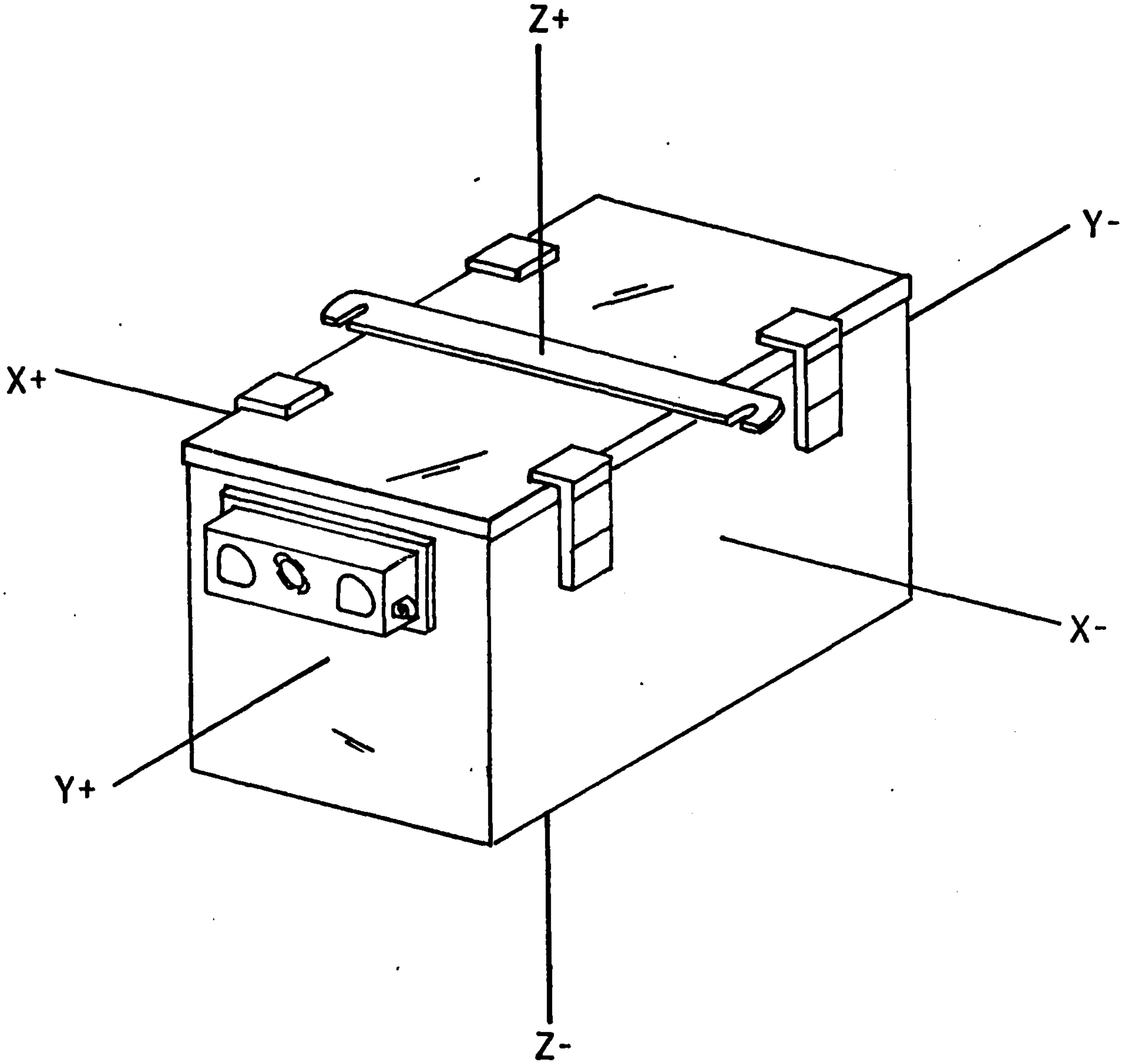
NON OPERATING TESTS	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	*6
Humidity	Procedure II, Method 507 MIL-STD-810			X			
Temperature Shock	Procedure I, Method 503 MIL-STD-810	X					
Sand & Dust	Procedure I, Method 519 MIL-STD-810				X		
Salt Fog	Procedure I, Method 509, MIL-STD-810					X	
Fungus	Procedure I, Method 508.1 MIL-STD-810	X					
OPERATING TESTS							
Mechanical Shock	Procedure I, Method 516 MIL-STD-810. The shock test shall be a half sine wave with a 15g peak and a duration of .011 seconds.	X					
Vibration	Battery shall perform normally during vibration of 10 to 500 Hz with input of .036 inch double amplitude or 10g whichever is the limiting factor. Vibration shall be applied in the normal upright position for 30 minutes.		X				
Attitude	Battery discharge performance shall not be affected by an angle of 60^{o} minimum from either horizontal axis.		X				
Altitude	Battery discharge shall not be affected by operation at altitudes up to 60,000 ft., and climb to or dive from this altitude in a period of 15 min.	X					

* Spare battery

TABLE 38(continued)

MAR-5011 QUALIFICATION TESTING

OPERATING TESTS (continued)	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	6
Acceleration	The battery shall perform normally during accelerations of 7.5g along the +Y,-Y,+Y, -Y, and +Z axis for 1.0 sec.		X				
Low Temperature	The battery shall be discharged at temperatures of 30°F, 0°F, -10°F, and -20°F to determine the effect of temperature on battery capacity.			X	X		
High Temperature	The battery shall be discharged at temperatures of 120°F, 140°F, to determine the effect of temperature on battery capacity.			X	X		
Cycle Life	The battery shall be cycled at a two (2) to three (3) hour rate of discharge to an 80% DOD until the battery will no longer deliver 80% of rated capacity above 20.2 volts. The battery shall be subjected to one (1) 35± 5 Amp discharge and one (1) 80±5 amp discharge near the middle or end of cycle life test for characterization purposes.						X



BATTERY ORIENTATION
MAR-5011

FIGURE 35

4.0 MANUFACTURE OF MAR-5011

4.2 Qualification Batteries (continued)

The MAR-5011 Qualification Batteries were the first batteries to be activated since the first group of MAR-5013 Flight Batteries. The MAR-5011 batteries were manually activated and allowed to soak 72 hours prior to charging. During this soak period, the electrolyte was maintained over the top of the separation instead of between the top of the plates and the top of the separation as in the MAR-5013 Flight Batteries. This elevated electrolyte level insured a properly "wet" cell before charging, and also helped to reduce the foaming problems encountered with the MAR-5013 Flight batteries. The wetting agent of Celgard 3400 separation is a surfactant. Battery activation with elevated electrolyte levels made it possible to remove more of the surfactant and reduce foaming. The MAR-5011 Qualification Batteries did not exhibit signs of foaming during formation. The final electrolyte level was adjusted between the top of the plates and the top of the separation during the formation charge.

Battery formation was conducted at 8 Amps constant current. Capacity input was 150 percent of theoretical capacity. The batteries were discharged at 26 amps constant resistance. Discharge capacities for the first two (2) cycles are listed in Table 39. Discharge was concluded when one cell in a battery reached 1.35 volts.

TABLE 39

MAR-5011 QUALIFICATION BATTERIES-DISCHARGE CAPACITIES

TEST SPECIMEN NUMBER	AH CAPACITY REMOVED	
	Discharge 1	Discharge 2
1	28.9	30.8
2	26.7	27.5
3	47.3	50.5
4	51.9	48.2
5	39.5	46.2
6	27.4	

As indicated by the table, a dramatic difference in battery capacity performance is seen between batteries containing electrochemical positive electrodes and batteries containing conventional positive electrodes.

4.2.1 Non Operating Tests

Battery testing for the non-operating portion of qualification testing is described as follows:

4.2.1.1 Humidity

Humidity testing was successfully completed on Test Specimen 3 on 16 January 1981. At the conclusion of testing, no signs of physical damage, or mechanical damage were evidenced.

Testing was conducted with the battery in the discharged condition. The battery was discharged on 15 October, 4.2.1 Non-Operating Tests (continued)

4.2.1.1 Humidity (continued)

1980. At the conclusion of humidity testing, final open circuit cell voltages were low as expected. The length of time the battery had sat discharged and exposure to elevated warm temperatures during humidity testing contributed to the low final open circuit voltages.

Following humidity testing the battery was charged and subjected to a twenty-four (24) amp constant resistance discharge. The battery delivered 52.3 Amp Hours to a battery cut-off voltage of 20.4 volts. Discharge cut-off voltage for a MAR-5011 battery is 20.2 volts. NOTE: This cycle following humidity testing was not required, the battery was cycled for informational purposes.

4.2.1.2 Temperature Shock

Test Specimen 1 successfully completed temperature shock testing on 11 November 1980. Testing was conducted with the battery in the discharged condition. The battery was discharged on 3 October 1980. At the conclusion of testing, visual examination of the battery did not indicate any evidence of physical or mechanical damage.

4.2.1 Non-Operating Tests

4.2.1.3 Sand and Dust

Sand and Dust testing was successfully completed on Test Specimen 3 on 6 January, 1981, (see attached data sheet). Visual examination of the battery did not indicate evidence of physical or mechanical damage.

4.2.1.4 Salt Fog

Test Specimen 5 completed Salt Fog Testing on 21 January 1981. Battery open circuits at the conclusion of testing remained normal. A very small "speck" of rust was observable on one container latch around the hinge area.

The battery cover gasket was found to be loose in one area when the battery cover was removed. Closer examination of the gasket revealed an insufficient amount of adhesive had been applied to the cover gasket in that area. None of the other gaskets in the five (5) other qualification batteries were loose.

4.2.1 Non-Operating Tests

4.2.1.5 Fungus

Test Specimen 1 successfully completed Fungus Testing on 1 April 1981. Testing of the MAR-5011 was conducted simultaneously with the MAR-5013. Refer to section I, paragraph 3.5.1.5 for test description. Following fungus testing the battery was charged and subjected to a 35 amp discharge until one cell in the battery reached 1.35 volts. The battery delivered 31.5 Amp hours. This discharge was not a requirement of fungus testing.

4.2.2 Operating Tests

Battery testing for the operating portion of qualification testing is described as follows:

4.2.2.1 Mechanical Shock

Test Specimen 1 successfully completed Mechanical Shock Testing on 23 December. The battery was charged at 8 amps constant current and sat open circuit for 23 hours 50 minutes prior to mechanical shock testing.

The battery was overtested during shock test application. The intended shock pulse was a half sine wave with a 15g peak and a duration of .011 seconds, in actuality, testing occurred at a 25.5 g peak. Shock application occurred at one (1) minute intervals starting one (1) minute into discharge. Discharge (35.7 amp rate) was discontinued when one cell in the battery reached 1.35 volts. A total of 28.6 Amp hours was removed from the battery. Figure 36 is a graph of the discharge.

Examination of oscillograph tapes at the conclusion of testing did not indicate battery discharge electrical performance was affected by mechanical shock testing. The battery did not exhibit evidence of physical or mechanical damage.

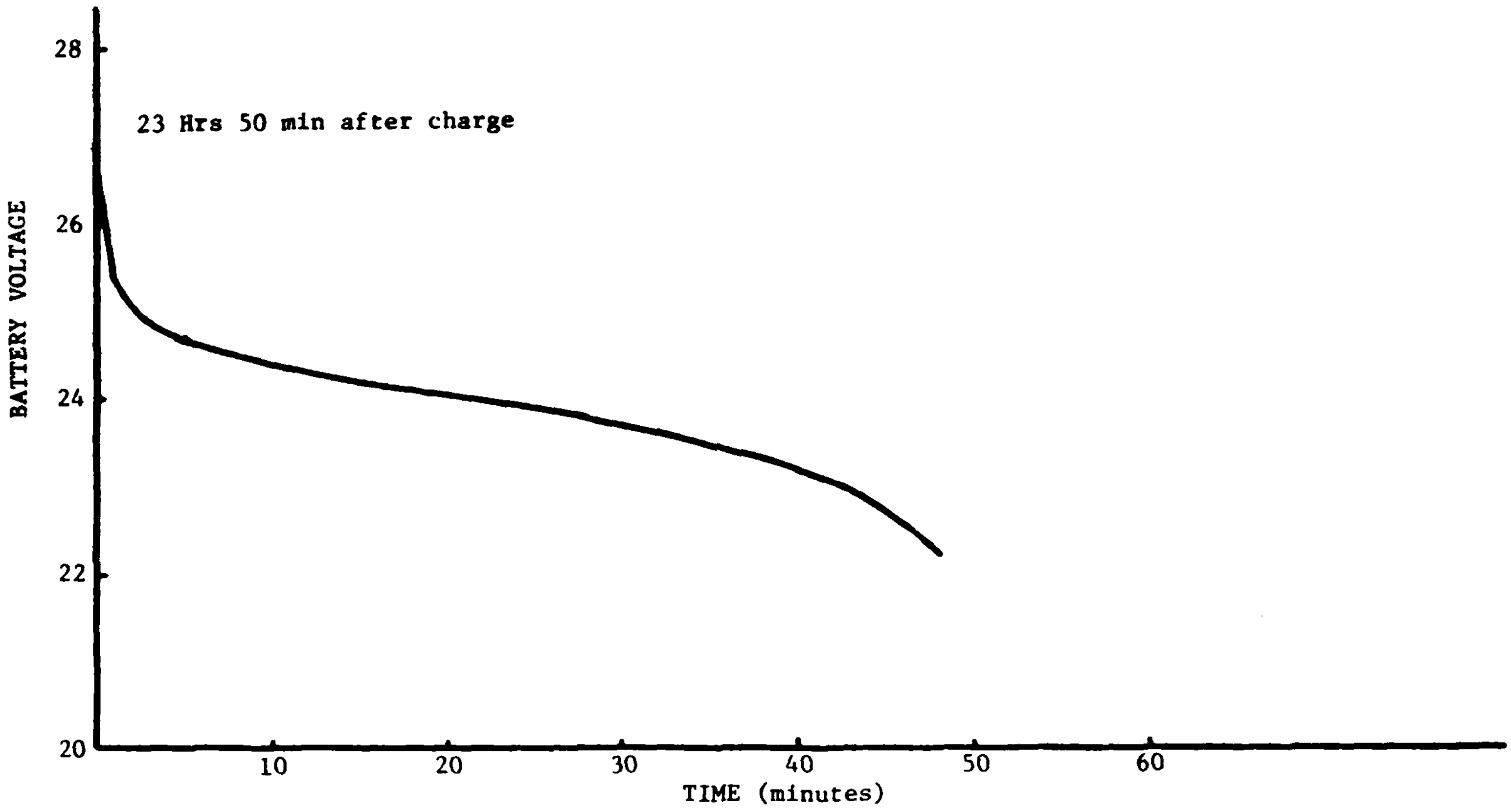


FIGURE 36

MECHANICAL SHOCK
TEST SPECIMEN 1
35.7 Amp Rate

4.2.2 Operating Tests (continued)

4.2.2.2 Vibration

Test Specimen 2 successfully completed vibration testing on 5 February 1981. Visual examination of the battery upon completion of testing, did not reveal any evidence of physical or mechanical damage. As a further method of inspecting the battery for damage (not required), the cells were individually leak checked. No evidence of cell leakage was detected. MAR-5011 cells are potted in the battery container. Figure 37 is a graph of the vibration discharges.

4.2.2.3 Attitude

Attitude testing was successfully conducted on Test Specimen 2 on 3 February, 1981. Discharge was conducted at approximated 30.5 amps constant resistance. Discharge was concluded when the first cell in the battery reached 1.35 volts. Figure 38 is a graph of the discharge.

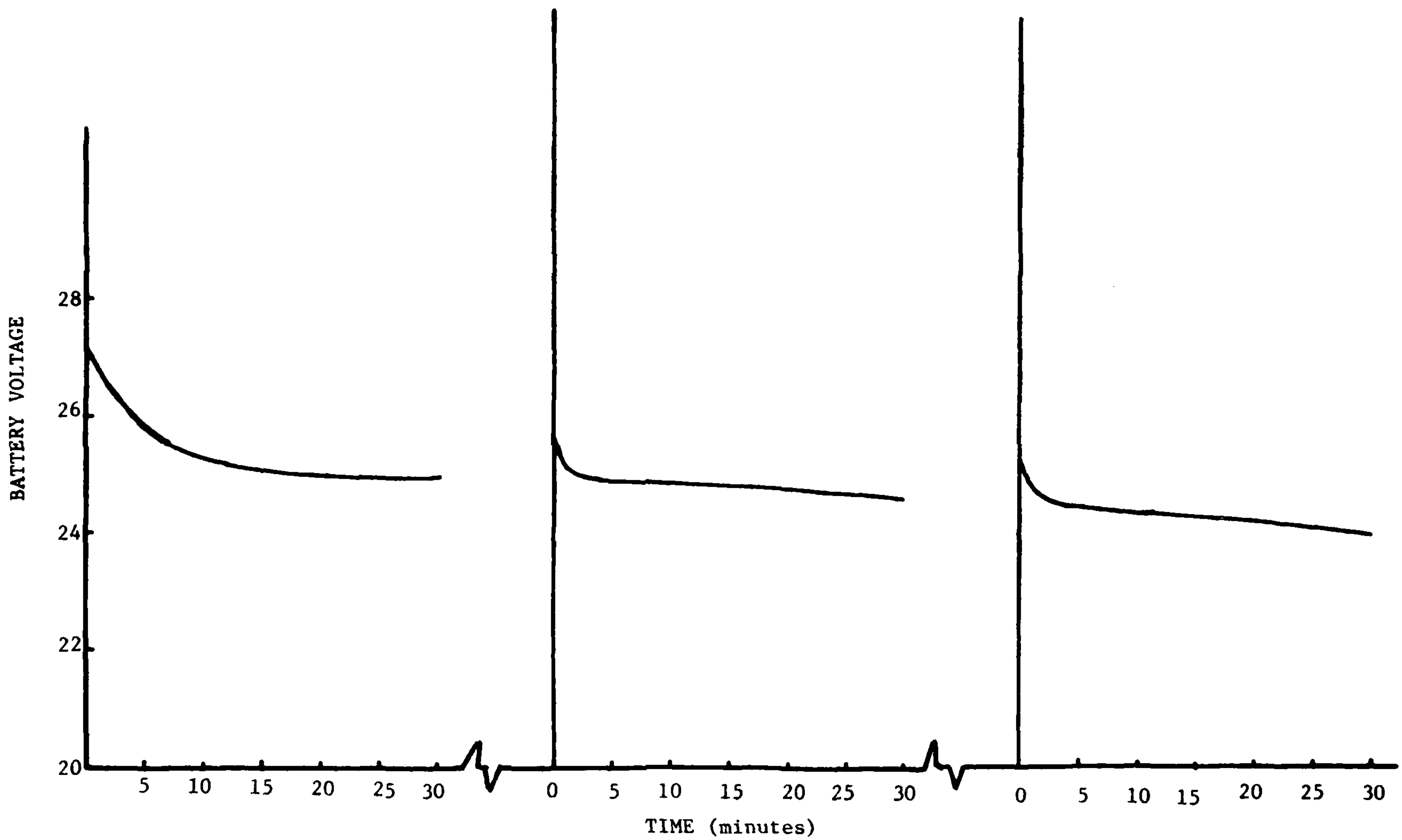


FIGURE 37
MAR-5011 VIBRATION
TEST SPECIMEN 2
15 Amp Rate

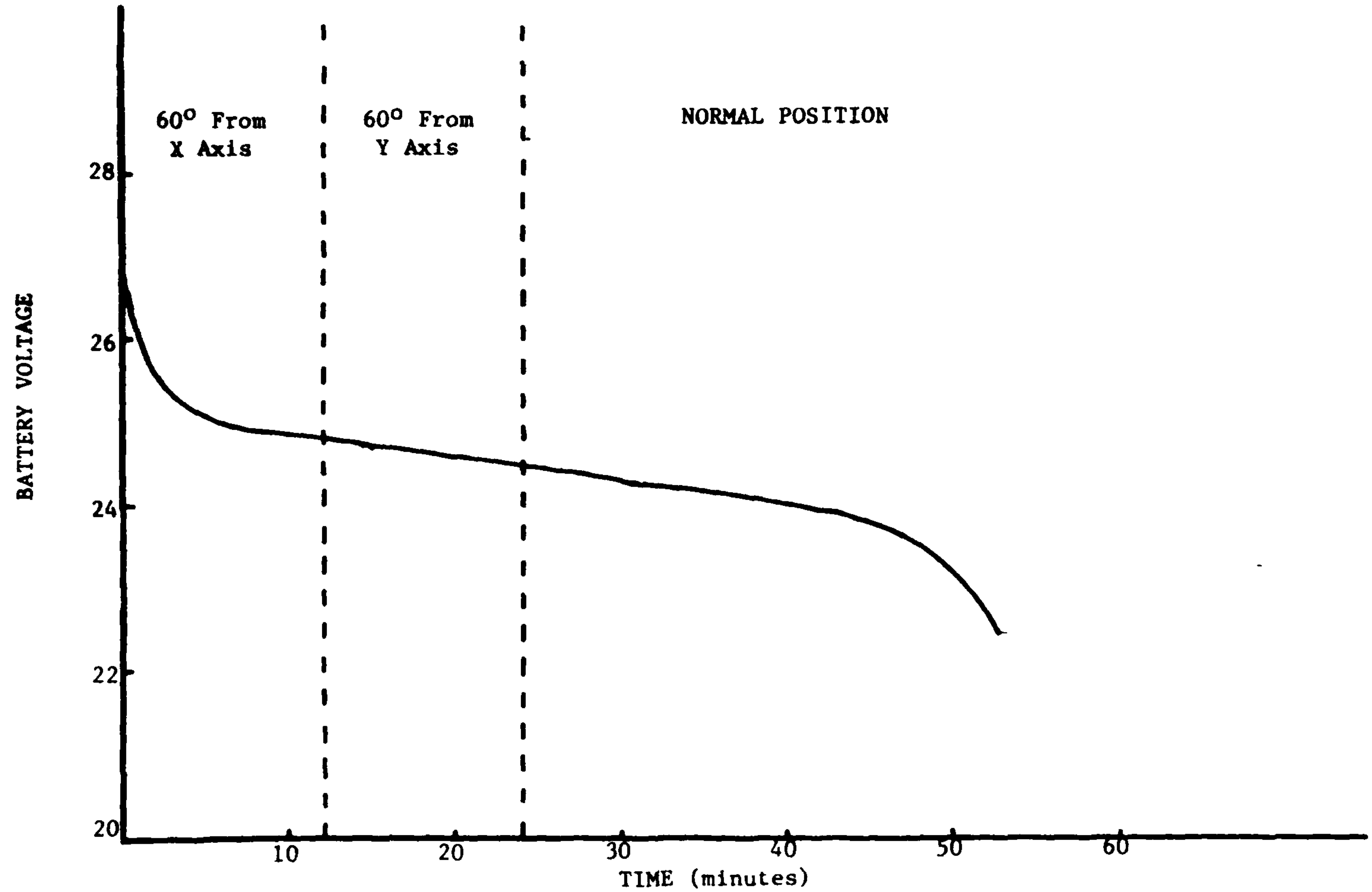


FIGURE 38

ATTITUDE

MAR-5011 TEST SPECIMEN 2
30.5 Amp Constant Resistance

4.2.2.4 Altitude

Altitude testing was successfully conducted on Test Specimen 1 on 5 January 1981. Battery discharge performance was not affected at a simulated altitude of 60,000 ft. Visual examination of the battery at the conclusion of testing did not reveal any evidence of physical or mechanical damage. No evidence of electrolyte leakage was detected. A total of 31.5 Amp-Hrs was removed from the battery to a battery cut-off voltage of 20.2 volts Figure 39 is a graph of the discharge.

4.2.2.5 Acceleration

Test Specimen 2 successfully completed acceleration testing on 17 March 1981. Visual examination of the battery at the conclusion of acceleration testing did not reveal any evidence of physical or mechanical damage. Examination of oscillograph tapes of battery discharge during acceleration did not indicate electrical performance was affected by acceleration testing. Following acceleration discharge was continued at a 35 amp rate. Battery performance was normal.

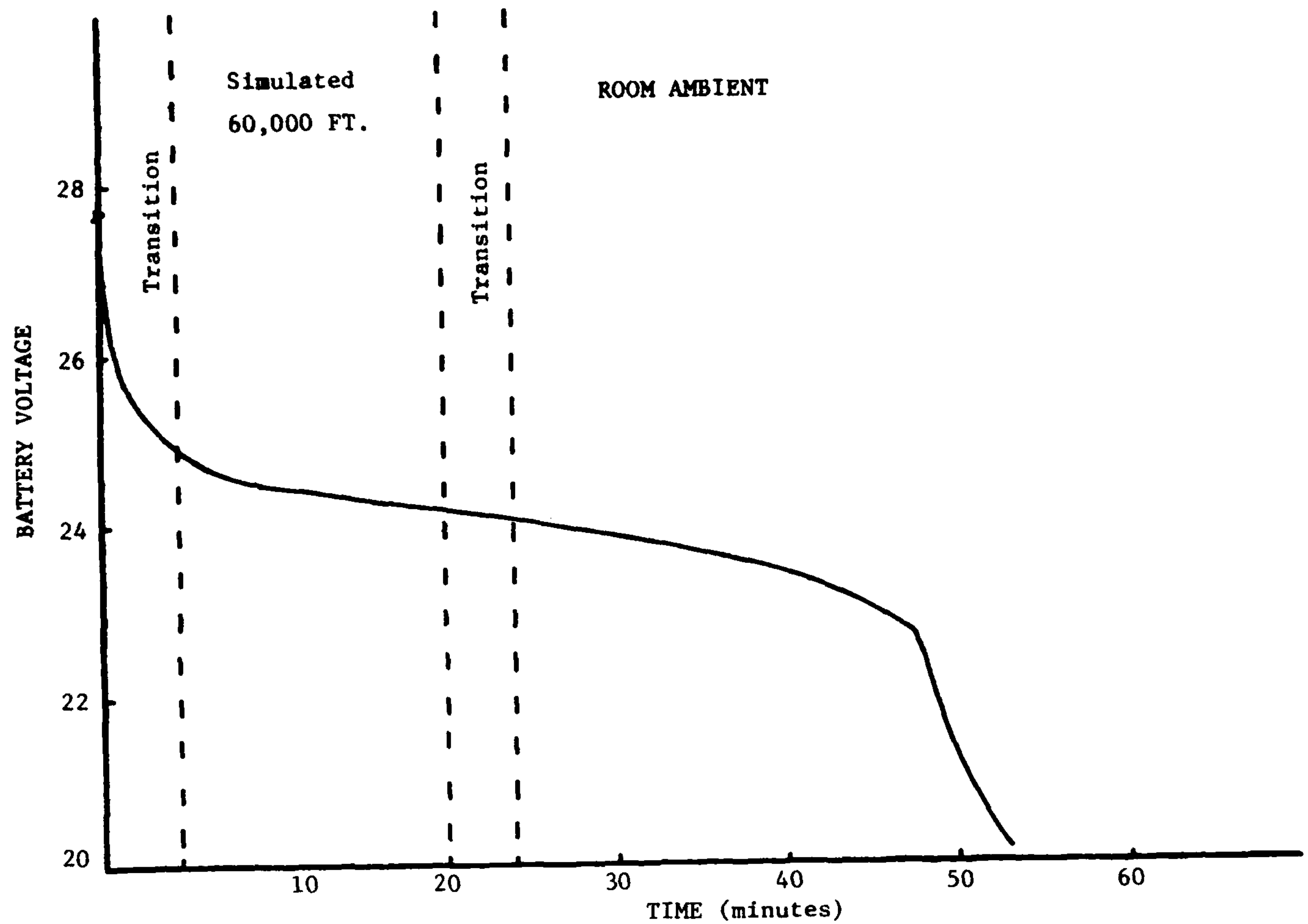


FIGURE 39

ALTITUDE
MAR-5011 TEST SPECIMEN 1
35.7 Amps

4.2.2.6 Low Temperature

Test Specimens 3 and 4 were subjected to low temperature testing to determine the effect of temperature on the battery's voltage and capacity. Low temperature testing was not required for battery qualification, but included by Eagle-Picher for performance characterization purposes. Battery cut-off voltage for the MAR-5011 is 20.2 volts. The existing PQM-102 battery has an 18 AH service capacity requirement, the MAR-5011 battery delivered greater than 18 AH at all test regimes with the exception of 30°F 80 amps. Test data is summarized in Table 40.

TABLE 40
MAR-5011 LOW TEMPERATURE PERFORMANCE

Temperature	Specimen 3		Specimen 4	
	Capacity (AH)	Final Voltage (volts)	Capacity (AH)	Final Voltage (volts)
30°F	42.6	21.6	43.7	20.8
0°F	42.6	20.2	43.4	20.2
-10°F	29.6	22.2	29.0	20.2
-20°F	36.8	20.2	26.6	21.0
30°F - 80 Amps	13.3	20.2	8.0	20.3
RT - 80 Amps	40.0	20.2	39.6	20.2

4.2.2.7 High Temperature

Test Specimens 3 and 4 were subjected to high temperature testing to determine the effect of temperature on the battery's voltage and capacity. High temperature testing was not required for battery qualification, but included by Eagle-Picher for performance characterization purposes. Battery cut-off voltage for the MAR-5011 is 20.2 volts. The MAR-5011 exceeded the existing PQM-102 battery's 18 AH service capacity requirement. Test data is summarized in Table 40.

TABLE 41

MAR-5011 HIGH TEMPERATURE PERFORMANCE

Temperature	Specimen 3		Specimen 4	
	Capacity (AH)	Final Voltage	Capacity (AH)	Final Voltage
120°F	46.1	20.2	45.5	20.2
140°F	40.3	20.9	44.3	22.8

4.2.2.8 Cycle Life

Test Specimen 5 was subjected to cycle life testing from 9 January 1981 to 15 August 1981. Testing was concluded due to alloted contract test time rather than battery performance. The battery completed 75 cycles at or greater than an 80 percent DOD (32 AH). Cycle testing required battery discharge to be conducted within two to three hours, therefore, routine cycle testing discharges were conducted at a twelve (12) amp rate for two (2) hours and forty (40) minutes. The battery was tested on automatic cycle equipment which normally switched directly from charge into discharge.

Discharge test data is summarized in Table 42. Figure 40 is graphic representation of cycle 3 conducted at 35.0 Amps. Discharge cycle 11 and 59 at the 12.0 Amp rate is shown in Figure 41. Battery discharge performance for the first 59 cycles was normal. Cell 99 shorted between cycle 59 and cycle 60. Examination of past performance data for cell 99 did not indicate any detectable performance deviations as compared to the other cells in the battery. Since battery performance had been very good up until this point, testing of the battery was continued by taking cell 99 out of series with the other cells. Cells in the MAR-5011 battery are potted in solid, and a post mortem on cell 99 was delayed until battery testing was completed. A

4.2.2.8 Cycle Life (continued)

post mortem cell examination required battery dissection. Battery cycle test cutoff voltage with cell 99 removed (14 cells) was 18.9 volts instead of 20.2 volts (15 cells). Discharge 60 was conducted at a 35.0 Amp rate. The battery delivered 37.3 AH to the 18.9 cut-off voltage. Cell 101 shorted between discharge 60 and charge 61. As in the case of cell 99, past performance data for cell 101 did not indicate performance abnormalities in cell 101 prior to shortage. Cell 101 was taken out of series and testing was continued. Battery cycle test cut-off voltage was now 17.5 volts (13 cells) instead of 18.9 volts (14 cells). Testing of the thirteen cell battery was continued for three reasons: first, overall battery performance was still good and well above the battery test cut-off voltage; second; it was desirable to continue testing to determine if additional cells would short as unexpectedly as cells 99 and 101 did since this was the only battery out of all the MAR-5011's and the MAR-5013's that developed shorted cells; and third, there was insufficient time remaining in the contract to begin cycle testing again.

Discharge 61 was conducted at an 80.0 amp rate. The battery delivered 32.0 AH to a cut-off voltage of 17.6 volts (battery cut-off voltage for the 13 cell battery

4.2.2.8 Cycle Life (continued)

was 17.5 volts).

Routine cycle testing at the 12 Amp rate of discharge was continued with cycle 62. At the conclusion of testing, battery discharge voltage remained well above the 17.5 volt cut-off.

Post mortem examination on cell 99 and cell 101 were conducted at the conclusion of testing. Cell 99 shorted due to a horizontal split in the Celgard, which could have possibly had a small split in it at the time of cell construction. The split was not caused by shape changes in the nickel electrodes. The cell failure mode for cell 101 was not located. The short could have been a "soft" short and was not observable because of the time span involved from the time the cell shorted and the time of cell examination. Overall, the appearance of both cell packs was very good with regards to 59 and 60 respective accumulated cycles. Of particular interest was examination of the conventional nickel electrodes. The chief concern in the incorporation of conventional nickel electrodes in the larger MAR-5011 cell was the increased possibility of more dramatic electrode shape changes which could result in separator penetration. The cells exhibited surprisingly little shape change. The appearance of the zinc electrode was

4.2.2.8 Cycle Life (continued)

normal with respect to cycle life.

Additionally, a post mortem examination was also conducted on a randomly selected operational cell, cell #105, for a comparison basis. Shape changes in the nickel electrodes again weren't as dramatic as expected for a cell with 76 cycles on it. The shape changes in the zinc electrode were as expected. The cell pack was still uniformly "wet" in appearance, particularly in regard to the Celgard material. Cell shortage in cell 99 and 101 appeared to be of a random nature and not directly reltated to cell design or overall battery performance. The conventional cycle life battery demonstrated a superior capacity cycle capacity retention when compared to the calendar and cycle life batteries with electrochemical nickel electrodes.

TABLE 42

MAR-5011 QUALIFICATION CYCLE LIFE
12 AMP RATE

CYCLE NUMBER	DISCHARGE CAPACITY (AH)	FINAL BATTERY VOLTAGE
1 (Formation)	44.9 (26 Amps Constant Resistance)	23.4
2	46.2 (26 Amps Constant Resistance)	22.7
3	46.0 (35.0 Amps)	22.0
4	32.0	25.0
6	32.0	24.6
11	32.0	24.7
14	32.0	24.3
17	32.0	24.2
18	32.0	24.3
25	32.0	24.0
30	32.0	24.0
32	32.0	23.8
40	32.0	23.9
43	32.0	23.8
48	32.0	23.8
50	32.0	23.5
59	32.0	23.5
Cell #99 shorted. Cell #99 taken out of series.		
Discharge cut-off now 18.9 volts, instead of 20.2 volts.		
60	37.3 (35 Amps-see data sheet)	18.9
Cell #101 shorted. Cell #101 taken out of series.		
Discharge cut-off now 17.5 volts instead of 18.9 volts.		
61	32.0 (80 amps-see data sheet)	17.6

TABLE 42 (continued)
MAR-5011 QUALIFICATION CYCLE LIFE

12 AMP RATE

CYCLE NUMBER	DISCHARGE CAPACITY (AH)	FINAL BATTERY VOLTAGE
62	32.0	20.2
63	32.0	20.7
65	32.0	20.5
66	32.0	20.6
68	32.0	20.3
69	32.0	20.2
71	32.0	18.5
72	32.0	20.4
73	32.0	20.3
75	22 (8 Amps)	21.0
76	32	20.1

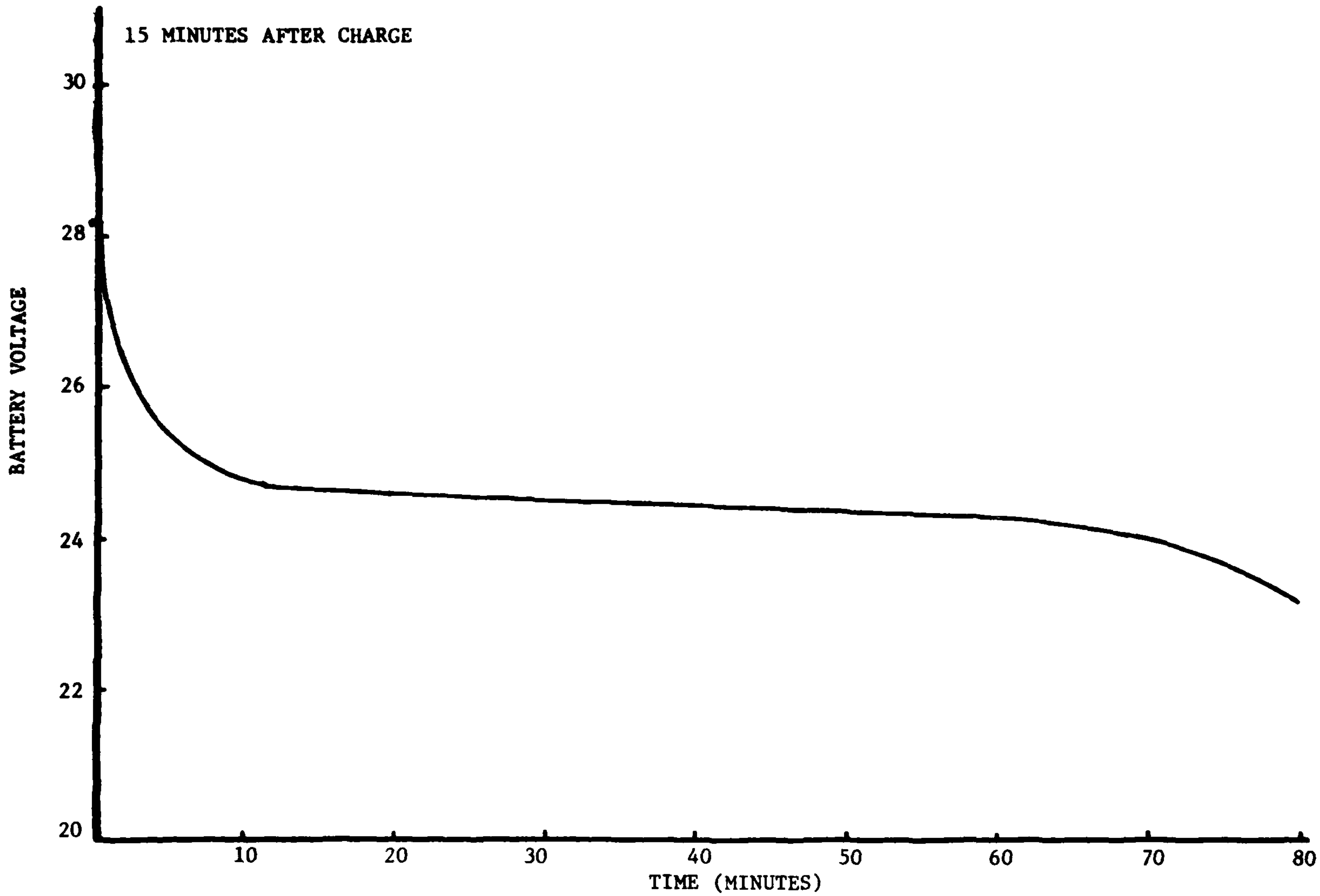


FIGURE 40
MAR-5011 CYCLE LIFE
TEST SPECIMEN 5
DISCHARGE 3 - 35.0 AMPS

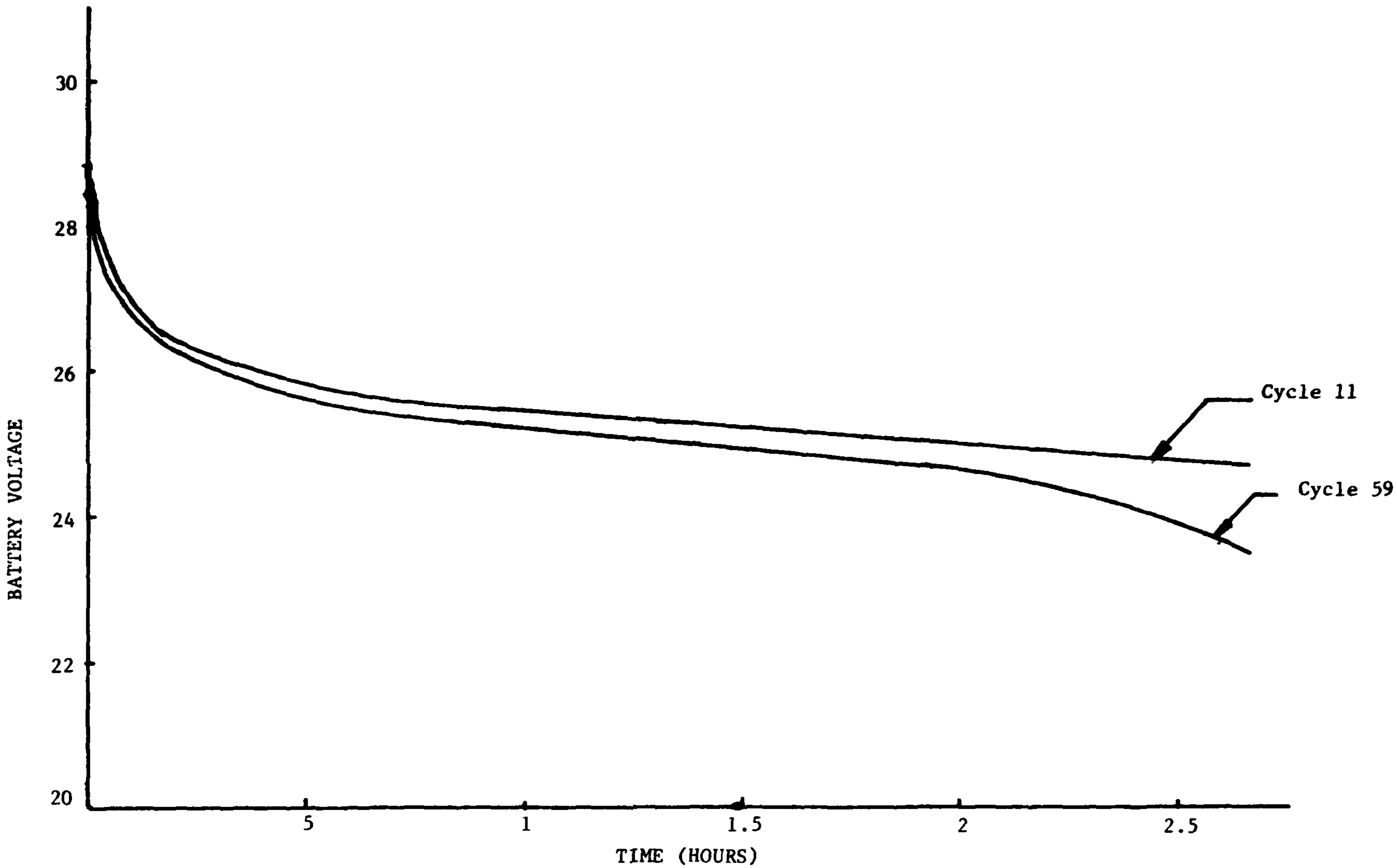


FIGURE 41
MAR-5011 CYCLE LIFE
TEST SPECIMEN 5
80 PERCENT DOD - 12 AMPS

4.3 MAR-5011 Flight Batteries

Fifteen (15) MAR-5011 flight batteries were constructed and shipped to Tyndall AFB during July 1981. All batteries were shipped in the unactivated condition. Cells were constructed with conventional positive electrodes. Copper grid and tab material was incorporated in the negatives. Refer to Table 32 for specific cell characteristics.

Flight testing was originally scheduled for July of 1981, however, scheduling problems at Tyndall have delayed Flight testing. At the conclusion of this reporting period actual Flight Testing at Tyndall is tentatively scheduled for December 1981.

5.0 SPECIAL SEPARATION BATTERIES

The construction of eight (8) Special Separation batteries for separator evaluation purposes was also included under this work effort. Testing of the batteries will be conducted at Wright-Patterson AFB, Ohio. Construction of the batteries was completed in July 1981, and the batteries were shipped to Wright-Patterson AFB in the dry, unactivated condition.

The eight (8) special separation batteries were of the same configuration as the MAR-5011 with the exception of internal cell design. Two separator systems were utilized in construction. The batteries were categorized by their specific separator system as follows:

Battery Serial Number	Separator Type
1-1, 1-2, 1-3, 1-4	+, pellon, 3400 Celgard, K317 Celgard (nickel coating facing zinc electrode), 2 layers 3400 Celgard, -pellon,
2-1, 2-2, 2-3, 2-4	+, pellon, 3400 Celgard, 2 layers K317 Celgard (nickel coated side face to face), 3400 Celgard, pellon,-

5.0 SPECIAL SEPARATION BATTERIES (continued)

Specific cell characteristics are listed in Table 43.

TABLE 43

SPECIAL SEPARATION BATTERIES- CELL CHARACTERISTICS

Configuration	6 Double Pos, 2 outside single/ 7 double neg.
Electrode Size:	6.30" X 2.96"
Positive Active Mat'l Loading:	.69 gm/in^2
Type Positive Electrode:	Electrochemical Impregnation on .025" Slurry Sinter
Positive Theoretical Capacity:	49.3
Negative Active Material Loading:	1.0 gm/in^2, no additives
Negative Electrode Thickness	.023"
Ratio Negative to Positive Theoretical Capacity	.30/1
Cell Surface Area: =	246 in^2

Electrodes were doubled in the cells because sufficient quantities of K317 Celgard (still in research stage) could not be obtained to allow for single electrode configuration. Electrochemical nickel electrodes were incorporated in the cells because they were already in stock and separator variables, rather than capacity, is of prime interest in those batteries. The primary purpose of these investigations will be to determine the effectiveness of the K317 Celgard (nickelized) in decreasing zinc dendrite formation within the cells.

At the conclusion of this reporting period, the batteries are in the unactivated condition.

SECTION III

SUMMARY AND CONCLUSIONS

Two nickel-zinc RPV batteries, the MAR-5013 and the MAR-5011, have been developed that offer respective viable alternatives to the standard RPV batteries currently in service on the BQM-34A and the PQM-102. The MAR-5013 has basically the same configuration and weight as the existing BQM-34A lead-acid battery, but is rated at 22.5 Ampere-Hours vs. 12.5 Ampere-Hours for the lead-acid battery. The MAR-5011 has the same configuration as the existing PQM-102 lead acid battery, but weighs 50 pounds vs. 56 pounds for the lead acid battery. Additionally, the MAR-5011 battery is rated at 40 Ampere-Hours vs. 18 Ampere-Hours for the lead acid battery. Currently, on the PQM-102, two lead acid batteries are paralleled to increase battery capacity to 36 Ampere-Hours. By using one MAR-5011, it would be possible to reduce RPV weight by 56 pounds and still have sufficient battery capacity to perform the required missions.

In summary, during the course of this program, two nickel-zinc batteries have been developed from the test cell stage to the point of successfully completing battery qualification programs. The capabilities were also evolved in this program to manufacture the two nickel-zinc batteries as production units. As evidence of this, the Flight Batteries for both the MAR-5013 and MAR-5011 were manufactured in production facilities. The basic overall intent of the program was not to necessarily make significant improvements in battery cycle life, but rather to bring the nickel zinc system out of the laboratory into actual field usage.

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